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In- Situ CBR Assessment of Subgrade in Flexible Pavement Mixed with Waste Tyre Scrap Material

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Abstract
This study deals with strength enhancement of flexible pavement subgrade using waste tyre scrap. It primarily evaluates the in-situ California Bearing Ratio (CBR) of subgrade clayey soil blended with tyre scrap. The study employs a mix of laboratory tests, including modified proctor and CBR tests, alongside the Dynamic Cone Penetration Test (DCPT) as a field method. The results show a marked improvement in the in-situ strength of the subgrade when tyre scrap is incorporated. Specifically, CBR values exhibited a substantial increase, rising from 3.82 to 9.21 with a 10% inclusion of tyre scrap of size 15mm×15mm, in the existing subgrade. This study underscores the efficacy of using tyre scrap as a sustainable and efficient material for pavement improvement. It not only presents a viable approach to managing waste tyre disposal but also contributes to the increased strength of pavement structures.

Keywords: *Pavement, Proctor, CBR, Subgrade, DCPT*

1. Introduction

The rapid growth in global vehicle numbers has brought about a concurrent increase in the production of waste tyres and tubes, a trend projected to result in approximately 2 billion scrap vehicles by 2030. This forecast, as outlined by Dargay et al. (2007), raises serious environmental and waste management concern. 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 (2012), highlighted that, tyre can release toxic substances, including polycyclic aromatic hydrocarbons, furans, dioxins, and nitrogen oxides, contributing to air pollution, unpleasant odors, and visual pollution. Incineration, while an alternative disposal method, also 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.(2015), has revealed the potential benefits of repurposing waste tyres. These recycled materials exhibit high tensile strength, durability, toughness, and resistance to aging, presenting a promising solution for environmental concern. 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 pavement hinges on several factors, including the strength of the subgrade soil, material quality, layer thickness, environmental conditions, and traffic characterization. To ensure the structural integrity and load-bearing capacity of the pavement, subgrade is crucial for distributing loads effectively. **This study focuses on comparing the strength 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 obtained 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 laboratory and in-situ CBR of subgrade of existing pavement and modified pavement. In the present work, Dynamic cone penetration tests (DCPT) tests have been conducted along the existing and modified pavements to assess the in-situ strength or CBR of subgrade. Recent studies in geotechnical and transportation engineering underscore the importance of DCPT. Vakili et al. (2021), demonstrated that adding lime to marl soil improved its mechanical properties, including UCS and CBR, validating effectiveness of DCPT in soil behaviour analysis. Wilches et al. (2020), studied the characterization of subgrade soils for urban roads in Northern Colombia. The researchers conducted 46 geotechnical surveys, utilizing both field tests (like the DCP) and laboratory tests (including CBR). Their dataset includes diverse soil types such as fat clay, lean clay, elastic silt, and others. This research is significant for its utility in predicting soil bearing capacity and informing effective pavement design, particularly in regions with similar geotechnical and socioeconomic characteristics to the study area. Lee et al. (2019), evaluated subgrade strength using an instrumented dynamic cone penetrometer (DCP). It highlights the limitations of standard DCPs and introduces an advanced version with a load cell and accelerometer at the cone tip. The instrumented DCP measures dynamic responses and calculates the dynamic cone resistance as a new strength index. Tests on weathered soils indicate this method offers a more reliable subgrade strength profile, with potential for improved pavement design and construction quality assurance. Nwanya and Okeke (2018), 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 layers of loose, medium, and dense soils. CBR values increased from 5% to 16% with depth, while average bearing pressures rose significantly from 104.8 to 301.1 KN/m^2, indicating increasing soil strength with depth. Sahoo and Reddy (2018), studied, on using DCPT to estimate soil strength, specifically targeting the relationship between DCPT and CBR values in fine-grained soils. They conducted laboratory experiments to explore the correlation between CBR values and DCP penetration depth across different fine-grained soil types. Their results indicated a strong correlation between CBR and DCP values for each soil type and across the combined data set. 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 strong link between CBR and DCPT values. These studies collectively contribute to a deeper understanding of pavement engineering, offering innovative methodologies for assessing, designing, and maintaining pavement performance. Al-Obaidi and Al-Ashoishi (2018) 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 California Bearing Ratios (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.

In this study the use of dynamic cone penetrometer (DCP) is emphasized for determining soil strength profiles, referencing Du et al. (2016). The DCP test is highlighted for its speed, simplicity, and portability, particularly useful for characterizing granular materials in the field. The concept of the dynamic cone penetration index (DCPI) as a strength index is introduced, noting its dependency on the observer's precision and potential variability. The modification underscores the importance of careful observation and maintaining the vertical alignment of DCPT during testing to ensure reliable readings.

The research extensively investigates the potential of using waste tyre scrap to enhance the strength of soft cohesive subgrade in flexible pavement. This study primarily focuses on evaluating the improvement in subgrade strength, particularly in terms of the CBR, by incorporating waste tyre scrap. To thoroughly assess this, both laboratory tests and in-situ CBR evaluations are conducted. The study compares the effect of tyre scrap on the subgrade of flexible pavements, aiming to provide a comprehensive understanding of how waste tyre materials can be effectively utilized in pavement construction to enhance its strength and durability. This approach not only seeks to improve pavement quality but also contributes to environmental sustainability by repurposing waste materials.

BACKGROUND OF THE PRESENT STUDY

In the present work, the necessary data for further analysis was obtained from outcome of 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 were collected, along the road, described as 'brownish grey silty clay,' 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 (from 10 mm x 10 mm to 30 mm x 30 mm) mixed with the 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% weight of the soil. **Based on these findings, a 30m long and 5.5m wide flexible pavement section was constructed at a distance of 20 m from the existing pavement**. The model pavement was constructed by utilizing an optimal mix of tyre scrap (15 mm x 15 mm) at 10% by 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 both the original and modified pavements is detailed in Table 1.

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

Category	Layers	Pavement thickness of existing road Subgrade	Pavement thickness 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	

According to the data from Table 1, it is clear that the thickness of the modified pavement has been reduced by 90mm compared to the original, untreated pavement.

2. 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.In the current study, a specific 30 m stretch of the Jibantala-Taldi Road, precisely between the 3.00 km to 3.03 km chainage was selected. This segment was selected due to its CBR value at 3.00 km, which was 3.39 as per laboratory tests. This value is notably close to the target design value of 3.36, ensuring that the segment is representative for subgrade strength of the entire road. The modified model pavement length was 30m, hence for further study 30m length was considered for the old pavement also. 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.

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

3. Experimental Studies

An attempt has also been made to carry out experimental studies in the laboratory by performing Modified Proctor Compaction as per IS: 2720 (PART 8): 1983 and CBR tests as per IS: 2720 (PART 8): 1983, on samples collected from four chainages mentioned in Table 2. In this context, it is notable that the existing road under study (Jibantala - Taldi) falls under the major district road category as per PWD. Therefore, Modified Proctor Compaction test has been adopted to determine the OMC and MDD.

The respective soil samples, which was 'brownish grey silty clay' have been collected from different chainage locations as specified in Table 2, and brought to the Soil Mechanics Laboratory of Jadavpur University, for further analysis. It is notable that, for modified pavement the collected sample was tyre mix soil sample. Modified proctor and CBR tests were performed on the collected samples. CBR test is used to measure the load-bearing capacity and strength of the road subgrade. The results of these laboratory tests at the specified chainage have been illustrated in Table 3.

4.1 Laboratory study

Table 3. Modified proctor and CBR test results for existing and scrap tyre modified subgrade pavement

Sl. No	Chainage (in 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	3.4
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	1.72	3.37

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4	3.03×10^3m	R/S	Brownish Grey silty clay	17.06	1.72	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	8.8

4.1.1 Discussion on Laboratory test results

Figure 1 and 2 shows the modified proctor and CBR curve respectively for both the pavements.

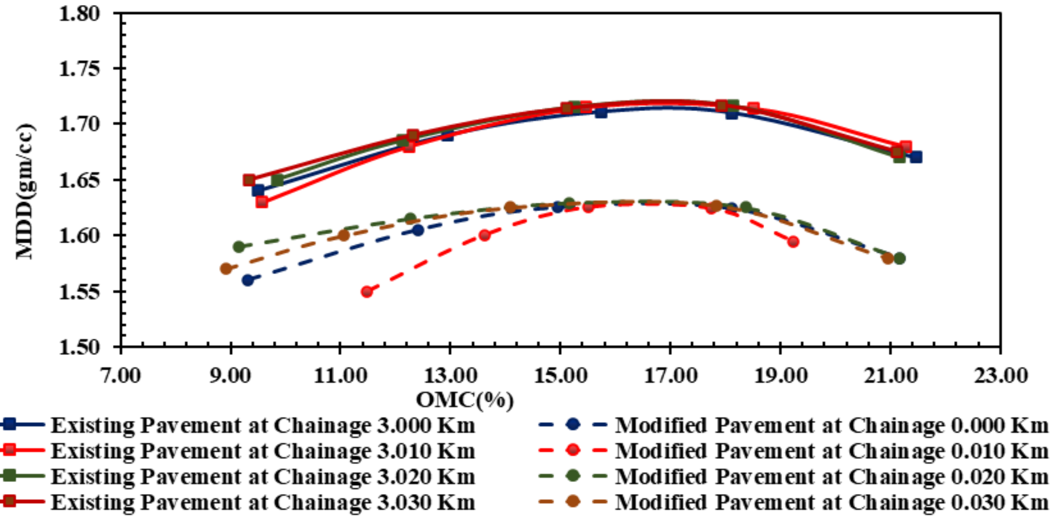

Fig.1 Variation in modified proctor for different pavements

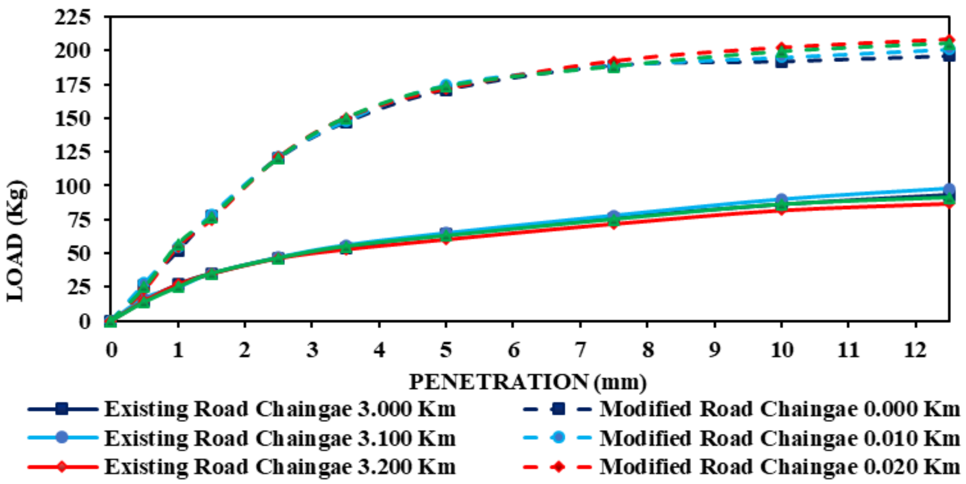

Fig.2 Variation in CBR for different pavements

The observations from Table 3 and Fig.1 indicate that the Maximum Dry Density (MDD) of soil mixed with shredded tyre scrap shows a marginal decrease. This decrease is primarily due to the lower density of waste tyres compared to that of clayey soil. The high absorption capacity of waste tyre scrap contributes to an increase in Optimum Moisture Content (OMC), as the proportion of tyre content increases, corroborating findings by Md. Zain et al. and Akbarimehr et al. The research further reveals, as shown in Figure 2 and Table 3, that the optimal minimum soaked CBR value is 8.79 at a 10% inclusion rate of tyre scrap with a size of 15mm x 15mm. This represents a significant improvement of approximately 161% or 2.61 times, compared to the minimum soaked CBR value of 3.37 for the original soil, underscoring the substantial enhancement in subgrade strength due to the integration of tyre scrap.

5.1 Field study

In the current study, 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. This study presents the principle of dynamic cone resistance as a strength index determined by the instrumented DCP and a comparison between the laboratory and the instrumented DCP tests for both types of pavements.

5.1.1 Background

The development of the Dynamic Cone Penetrometer (DCP) for subgrade soil assessment began with Scala's creation of the Scala Penetrometer in Australia in 1956. This device, similar to the current DCP, featured a 9 kg hammer dropping from 510 mm to apply force onto a cone. Later, van Vuuren (1969) developed a comparable tool with a 10 kg hammer dropping from 460 mm, establishing a correlation between DCP results and CBR values. The Transvaal Roads Department in South Africa used a DCP in 1973 (Kleyn 1975) with an 8 kg hammer and 574 mm drop height, comparing cones with apex angles of 30° and 60°. Further studies by Kleyn and Savage (1982) involved similar configurations for subgrade testing.

5.1.2 Identification of test points in the present study

The test point locations were pre-identified, and points were computed for each project section. These sections were then subdivided based on the data from the visual pavement condition survey and test pit information. To account for various factors and establish comparability between the two pavements, both roads were partitioned into four equal parts for the purpose of conducting DCPT tests. All the DCPT test points with chainage are outlined in Table 2.

5.1.3 Determination of In-situ CBR from DCPT results

The Dynamic Cone Penetrometer (DCP) is a tool used for quickly assessing subgrade properties on-site in road construction. It is essential for determining the subgrade ability to support the pavement over it. The central thrust of this investigation encompasses two primary objectives:

i. Thoroughly scrutinizing the engineering attributes of the subgrade soil through the utilization of the DCPT methodology.

ii. Conducting a comparative analysis between the results obtained from the DCPT and the laboratory-calculated CBR values.

For assessment of subgrade strength characteristics by DCPT, 1m x 1m test pits were excavated at 0.01km interval, 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 has been shown in Fig.3.

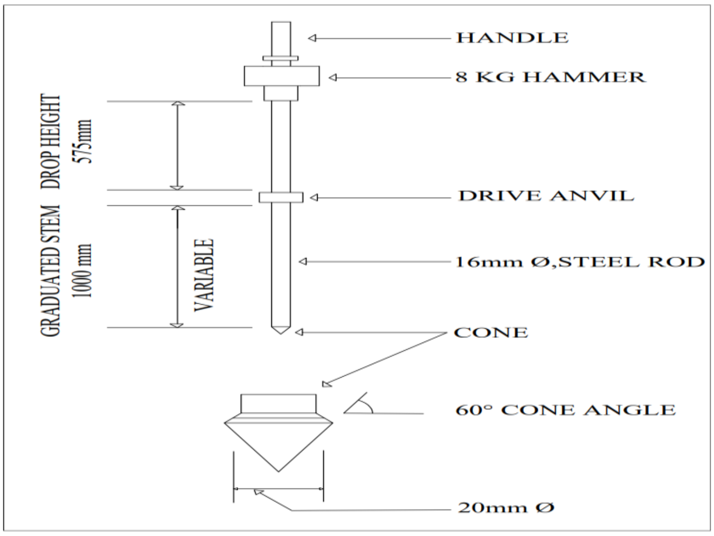

Fig.3 Schematic diagram of the DCP instrument [12]

Fig.3 illustrates the standard configuration of the DCP. In this configuration, the DCP comprises upper and lower shafts. The upper shaft houses an 8 kg drop hammer with a 575 mm drop height and is connected to the lower shaft via an anvil. The lower shaft includes an anvil and a cone fixed at the shaft's end, with the cone featuring a 60-degree angle. As a measuring device, an additional rod is affixed to the lower shaft, marked in millimetres. To operate the DCPT, two individuals are typically required. One operator releases the hammer, while the other records measurements. The test begins by placing the cone tip on the test surface. The lower shaft containing the cone moves independently from the reading rod, which rests on the test surface throughout the test. The initial reading is not typically zero due to the loose, disturbed state of the ground surface and the weight of the testing equipment. The value of this initial reading is considered the initial penetration, corresponding to blow zero.

5.1.4 DCPT mechanism

To operate the DCPT, two individuals are typically required. One operator releases the hammer, while the other records measurements. The test begins by placing the cone tip on the test surface. The lower shaft containing the cone moves independently from the reading rod, which rests on the test surface throughout the test. The initial reading is not typically zero due to the loose, disturbed state of the ground surface and the weight of the testing equipment. The value of this initial reading is considered the initial penetration, corresponding to blow zero. Fig. 4 displays the penetration result following the first hammer drop. Hammer blows are repeatedly applied, and the penetration depth is measured after each blow. This process continues until the desired penetration depth is achieved.

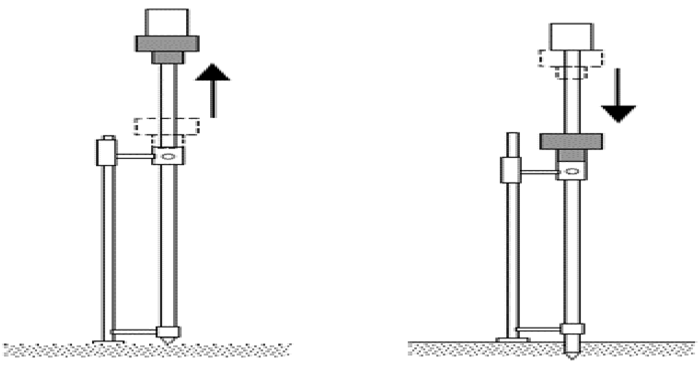

Figure 4. DCP test before and after hammer drooping effect.

5.1.5 Preparation of DCPT outcome data

The depth of penetration is measured after each impact, and the results of the DCPT test are expressed in terms of mm per blow (mm/blow). The advantages of using the DCPT include the rapid evaluation of subgrade strength and the ability to generate a substantial volume of data within a short timeframe. However, it is important to note that, as a correlation method, the DCPT may not provide laboratory-soaked CBR values. DCPT results consist of a number of blow counts versus penetration depth. Since the recorded blow counts are cumulative values, results of DCPT, in general, are given as incremental values defined as PI = ΔDp / ΔBC, where PI = DCP penetration index in units of length divided by blow count;

ΔDp = penetration depth;

BC = blow counts corresponding to penetration depth ΔDp.

As a result, values of the penetration index (PI) represent DCPT characteristics at certain depths.Fig.5 shows a typical DCPT results .

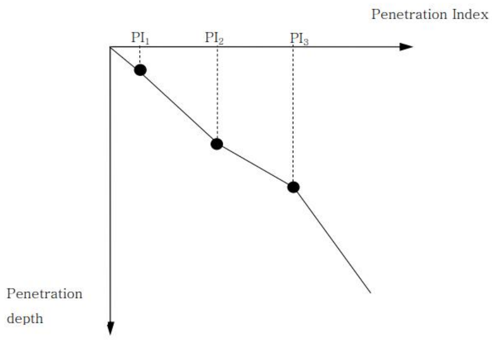

Figure 5. Typical DCP test result.

5.1.6 Relationship between Penetration Index (PI) and CBR Values

Several authors have investigated relationships between the DCP penetration index PI and California Bearing Ratio (CBR). CBR values are often used in road and pavement design. Two types of equations have been considered for the correlation between the PI and CBR. Those are the log-log and inverse equations. The log-log and inverse equations for the relationship can be expressed as the following general forms:

Research by various authors has focused on the relationship between the Dynamic Cone Penetrometer (DCP) Penetration Index (PI) and the California Bearing Ratio (CBR), commonly used in road and pavement design. To establish this correlation, two types of equations are considered: the log-log and inverse equations. These equations, in their general forms, express the correlation between PI and CBR, offering a mathematical framework to translate DCP measurements into CBR values for practical application in pavement engineering.

log-log equation: $\log CBR = A - B \cdot (\log PI)^c$ (1)

inverse equation: CBR = D(PI)E + F (2.3) (2)

where CBR = California Bearing Ratio; PI = penetration index obtained from DCPT in units of mm/blow or in/blow; A ,B, C, D, E, and F = regression constants for the relationships.

Harison's (1987) statistical analysis determined that the log-log equation is more reliable for correlating DCP Penetration Index (PI) and CBR compared to the inverse equation, which was found error-prone and unsuitable. Subsequent researchers, including Livneh in 1987 and 1989, have proposed different coefficients (A, B, and C) for the log-log equation based on their field and laboratory findings, further refining the equation for practical applications in pavement assessment and design.

$\log CBR = 20.2 - 71.0 \cdot (\log PI)$ (3)

$\log CBR = 14.2 - 69.0 \cdot (\log PI)$ (4)

where CBR = California Bearing Ratio; PI = DCP Penetration Index. Although equ. (4) was suggested based on eqn. (3), differences in results from eqn. (3) and eqn. (4) are small.

After further examination of results by other authors, Livneh et al. (1994) proposed the following equation as the best correlation:

logCBR = 46.2 − 12.1 ·(log PI) (5)

Table 4 summarizes typical log-log equations suggested by different authors for the CBR-PI correlation. The penetration for each blow has been noted down in the field data sheet and after that, the field CBR from the DCPT test has been calculated using the correlation between CBR and PI (Penetration Index), the correlation has been given in Table 4.

Table 4: Correlations between CBR and PI (After Harison 1987 and Gabr et al. 2000)

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
Harison (1987)	log(CBR)=3.03-1.54log(PI)	Laboratory	Granular
Livneh et. Al. (1994)	log(CBR)=2.46-1.12log(PI)	Field and Laboratory	Granular and Cohesive
Ese et. Al. (1994)	log(CBR)=2.44-1.07log(PI)	Field and Laboratory	Aggregate base course (ABC)
NCDOT (1998)	log(CBR)=2.60-1.07log(PI)	Field and Laboratory	ABC and Cohesive
Coonse (1999)	log(CBR)=2.53-1.14log(PI)	Laboratory	Piedomont residual soil
Gabr (2000)	log(CBR)=1.40-0.55log(PI)	Field and Laboratory	Aggregate base course (ABC)

The correlation for cohesive soil has been used to convert the DCPT into CBR. For the existing subgrade soil is appraised as cohesive soil by visual means, the correlation by Harrison formula has been used for the present purpose. Though, CBR has been calculated by formulas given by Klern (1975) and Livneh et al (1994) also to compare the CBR values which have been obtained by Harrison's (1987) formula. The summarised co-relation table has been illustrated in Table 5.

Table 5 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

5.1.7 DCPT test results for existing and modified pavements

The DCPT test results obtained by using 3 different methods as described in Table 5 are enlisted in Table 6.

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	3.00×10^3m	L/S	Brownish Grey silty clay	4.99	3.82	4.60	3.82
2	3.01×10^3m	L/S	Brownish Grey silty clay	5.01	3.83	4.62	3.83
3	3.02×10^3m	L/S	Brownish Grey silty clay	5.10	3.91	4.69	3.91
4	3.03×10^3m	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 Summary of DCPT test results

A sample DCPT results for the existing pavement at chainage 3.03×10^3 m are detailed as follows, it is notable that for further study the minimum CBR obtained from DCPT will be consider to get the worst scenario.

Chainage: 3.03×10^3m (RHS) on existing pavement

Table 7. DCPT test results at chainage - 3.03×10^3m

Sl. No	**No. of Blows**	**Cumulative no of Blows.**	**Scale Reading (mm)**	**Penetration (PI) (mm)**	**Point-to-point CBR**	**Poin to point CBR(Harrison)**	**Poin to point CBR (kleyn)**	**Point to point CBR(Livneh)**
1	0	0	6	0				
2	1	1	33	27	8	8	6	7
3	1	2	64	58	7	7	5	6
4	1	3	80	74	15	15	12	13
5	1	4	117	111	6	6	4	5
6	1	5	160	154	5	5	4	4
7	1	6	200	194	5	5	4	5
8	1	7	235	229	6	6	5	5
9	1	8	275	269	5	5	4	5
10	1	9	320	314	4	4	3	4

11	1	10	371	365	4	4	3	4
12	1	11	412	406	5	5	4	5
13	1	12	452	446	5	5	4	5
14	1	13	501	495	4	4	3	4

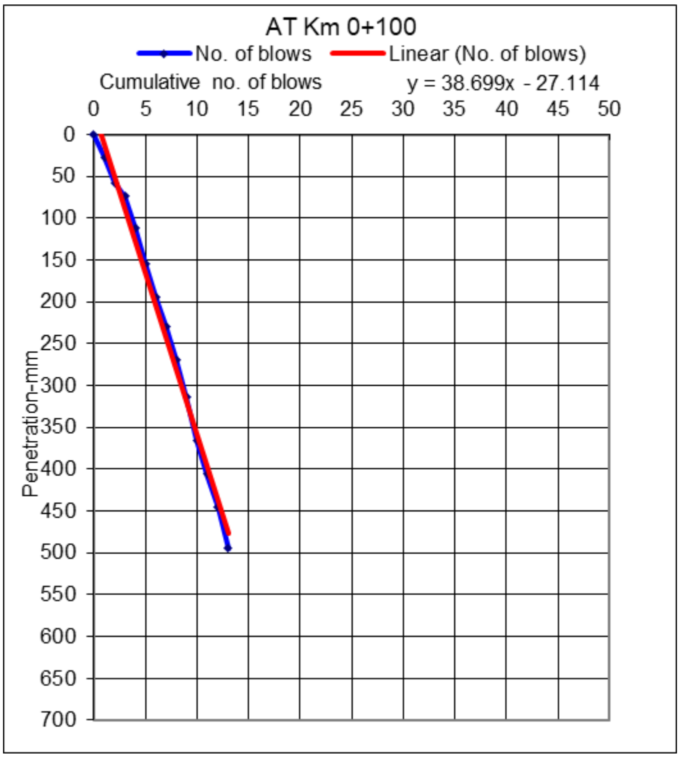

Figure 6. DCPT Test Result Graph at chainage 3.03×10^3m

Table 8. Summarised result of DCPT

Calculation of average CBR from Trend Line	
CBR(Harrison)	5.2
CBR(Kleyn)	4.0
CBR(Livneh)	4.8
Adopted DCPT CBR : 4.0	

5.1.8 Discussion on DCPT oriented in-situ CBR

Based on the above discussion, it is evident that, the DCP tests conducted along the road stretches, in-situ CBR values have been calculated. In-situ CBR, corresponding to laboratory CBR values and presented in Table 9. The focus will be on the comparison of laboratory and in-situ CBR values, as presented in Table 9.

Table 9. Comparison table between field and laboratory CBR

Sl. No	Chainage (in Km)	Lab CBR %(Soaked)	CBR from DCPT
CBR Values for existing pavement			
1	3.00	3.40	3.82

2	3.01	3.43	3.83
3	3.02	3.37	3.91
4	3.03	3.39	4.50
CBR Values for subgrade modified pavement			
3	0.00	8.79	9.21
4	0.01	8.84	9.30
5	0.02	8.83	9.33
7	0.03	8.80	9.40

A notable observation from the table has been noted, which is the difference in laboratory and in-situ CBR values, particularly for the tyre scrap modified subgrade pavement, indicating a substantial improvement in subgrade strength.

From Table 8, it has been observed 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. Fig.7 shows a comparison bar chart between in-situ CBR and Laboratory CBR.

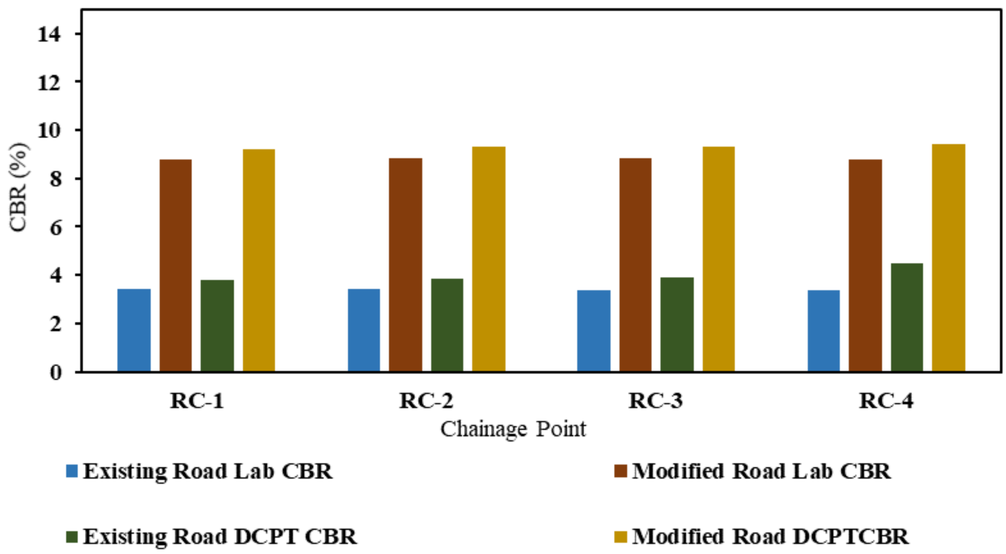

Figure 7. Comparison bar chart between Laboratory CBR and In-situ CBR

From Table 9 and Figure 7, it is evident from the data that there is no significant difference between the laboratory values and in-situ CBR values obtained from DCPT, for existing pavement. This may be due to the presence of nearby water bodies. In general, both laboratory and DCPT CBR values exhibit a consistent trend along the road stretch. In most instances, the DCPT CBR values slightly surpass the laboratory CBR values as studied by Bandyopadhyay and Bhattacharjee [16]. The original minimum in-situ CBR value mentioned is 3.82, which is the result 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. Furthermore, the correlation of these findings with Falling Weight Deflectometer (FWD) analysis, as per IRC 115:2014, should be explored. The FWD analysis is critical in understanding the subgrade strength and soil properties, which are vital for determining the pavement's deflection responses and calculating its elastic moduli. The discussion can also extend to the practical implications of these findings in road construction, maintenance, and design. For instance, the use of tyre scrap in subgrade improvement can be a sustainable practice, contributing to waste management and cost-effective road construction techniques. Additionally, exploring the broader context of these results in terms of pavement engineering and infrastructure development will provide a comprehensive understanding of the significance of the study.

6. Conclusion

I. It has been observed that for the existing pavement, there were no significant changes in the in-situ CBR as measured by the DCPT compared to the laboratory CBR values. This lack of variation in CBR for the existing pavement may be attributed to the influence of nearby water bodies, which could affect the in-situ CBR measurements. Conversely, for the modified pavement, there was an average increase of approximately 5% in the DCPT-measured CBR compared to the laboratory-measured CBR.

ii. The current study showed that incorporating 10% shredded rubber tyre, sized 15mm × 15mm, into the subgrade soil significantly improved its CBR value. This enhancement was observed in both laboratory measured and in-situ CBR values determined by DCPT. Specifically, for the modified pavement, the laboratory-measured CBR increased by 161% and the in-situ DCPT-measured CBR increased by 141%, compared to the existing pavement.

iii. The study highlights the significant improvement in the CBR values of subgrade soil when mixed with shredded rubber tyre.The modified pavement with tyre scrap shows a substantial increase in CBR values compared to the existing pavement, demonstrating the effectiveness of using waste tyre scrap in enhancing pavement subgrade strength. This approach not only offers a sustainable solution for waste tyre management but also contributes to the improvement of pavement durability and load-bearing capacity.

The conclusion of this study can be drawn from the analyses and results presented in the document. It highlights the significant improvement in the California Bearing Ratio (CBR) values of subgrade soil when mixed with shredded rubber tyre. This improvement is evident in both laboratory and in-situ tests, including the Dynamic Cone Penetration Test (DCPT). The modified pavement with tyre scrap shows a substantial increase in CBR values compared to the existing pavement, demonstrating the effectiveness of using waste tyre scrap in enhancing pavement subgrade strength. This approach not only offers a sustainable solution for waste tyre management but also contributes to the improvement of pavement durability and load-bearing capacity.

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