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A comparative study on rutting behavior of unbound and cement stabilized base layers in flexible pavements

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Abstract: **-** Rutting distress, a phenomenon characterized by formation of ruts in high-stress areas of flexible pavements, necessitates material enhancements due to increased vehicular loads resulting from national and international trade via highways, highlighting the need for revised prediction methods utilizing laboratory tests with standardized protocols to evaluate asphalt mixtures before field application. While pavement construction consumes substantial non-renewable resources, there's an increasing emphasis on sustainability over initial costs in government decision-making, underscoring the importance of sustainable development to reduce investments and preserve natural resources. Notably, cement-treated bases are effective in extending the fatigue life and reducing cracking in flexible pavements. Various testing devices, such as the Georgia loaded-wheel tester, French wheel tracking tester, Hamburg wheel-tracking device, and asphalt pavement analyser, assess asphalt mixture properties, but mainly target bound bituminous layers. This study's primary goal is to compare the rutting performance of two pavement sections using a novel device called the 'Roller compactor cum rut analyser' (RCRA), capable of compacting and analysing all layers of flexible pavement. By applying the RCRA model, the research demonstrates that the section with cement-stabilized layers displays enhanced resistance to rutting and deformation, providing valuable insights for the construction of durable road infrastructure.

Keywords*: flexible pavement, roller compaction, rutting, stabilized bases.*

1. Introduction

Rutting distress is a type of pavement depression that occurs along the wheel paths and is commonly observed in asphalt pavements that are subjected to high stress levels. To address this issue, it is necessary to improve the materials used in asphalt pavements. The increased loading magnitude and tire pressure of vehicles due to the growing trend of national and international trade through highways have necessitated a modification of classical methods for predicting asphalt mixture's field performance prior to laying them in the field. To rank different asphalt mixtures, several laboratory performance tests are used to simulate their field response under artificially controlled loading and environmental conditions. These tests are generally conducted according to their own defined standard protocols.

Various devices like Georgia loaded-wheel tester, French wheel tracking tester (FWTT), Hamburg wheel-tracking device, and asphalt pavement analyser (APA), assess asphalt mixture engineering properties including rutting resistance. Cooper wheel tracking test examines high-temperature plastic deformation susceptibility [1]. Hamburg wheel tracking device evaluates rutting and moisture damage [2]. Another comprehensive testing system, the simple performance test (SPT), demonstrates versatility by conducting three distinct uniaxial and triaxial compression tests: flow time, flow number, and dynamic modulus tests [3]. However, these tests mainly focus on bituminous mixture performance and overlook the cumulative effect of rutting across pavement layers. Conversely, compacting bituminous mix specimens through kneading action and evaluating them for rutting in the lab is intuitive. A rutting model was developed using laboratory rutting performance data obtained from the Hamburg Wheel Tracking Device (WTD) test. The model was a three-stage model that described the three different phases of HMA rutting that normally occur during the rutting test: consolidation (or primary stage), permanent deformation (or secondary stage), and flow (or tertiary stage). The model was based on a third-order polynomial, and the parameters of the polynomial model were related to the asphalt binder properties [2]. The model was used to evaluate the rutting performance of HMA pavements and identify the three different stages of rutting. In the primary zone, permanent deformations accumulate rapidly. The rate of permanent deformations then decreases, reaching a constant rate in the secondary zone. Finally, the permanent deformations accumulate rapidly again in the tertiary zone [4].

According to a study based on the VESYS mechanistic-empirical rut model, the contribution to the total rutting from various pavement layers was 57% from the bituminous bound layer surface layers, 27% from the base layers, and 16% from the sub-grade layer. These findings confirmed that the contribution to the total rutting from the bituminous bound surface layers and base layers was significant and should be incorporated into any mechanistic-empirical design procedure [5].

On the other hand, pavement construction consumes significant quantities of non-renewable resources like natural aggregates and fossil fuels, resulting in a substantial embodied energy in the pavement structure. This depletion of global non-renewable resources underscores the imperative for governments at all levels to prioritize sustainability when evaluating pavement structures, rather than focusing solely on initial costs [6]. Sustainable development should be considered vital because it helps to reduce investments, meet societal needs, save natural resources, maintain synchronization with natural resources and people, and retain the availability of natural resources for impending generations [7]. A study conducted with different stabilized bases in flexible pavements found that Portland cement-treated bases were the most effective at extending the fatigue life and reducing fatigue cracking in flexible pavement sections. $CaCl_2$ and bituminous-stabilized bases had a similar impact to the untreated RAP base on fatigue performance. Geo-grid-stabilized bases had the lowest impact on fatigue and rutting life, but the impact may vary based on factors like aggregate type [8].

2. Objectives

Considering all the above-mentioned gaps from literature, the main objective of the present study is to compare rutting performance of two pavement sections with the help of a novel equipment, 'Roller compactor cum rut analyser' (RCRA). This equipment is capable of accommodating all pavement layers within its mould by compacting individual layers with roller compaction aided by a kneading mechanism. The first pavement section, named 'PS-1,' comprises conventional flexible pavement layers housed in the RCRA mould. This provides accountability for the embedment of all pavement layers, including subgrade soil, granular sub-base (GSB), wet mix macadam base (WMM), dense bituminous macadam (DBM), and bituminous concrete (BC). The second pavement section, named 'PS-2,' comprises flexible pavement with stabilized bases housed in the RCRA mould. It includes subgrade soil, cement-treated sub-base (CTSB), cement-treated base (CTB), dense bituminous macadam (DBM), and bituminous concrete (BC).

3. Materials and methods

The soil used in pavement models PS-1 and PS-2 was collected from the Bengaluru region and had a specific gravity of 2.56. To analyse its particle size distribution, a comprehensive sieve analysis was performed using 10 different sieve sizes, ranging from 100 mm to 0.075 mm openings. The soil retained on the 4.75 mm sieve was subjected to dry testing, while the portion passing the 4.75 mm sieve and retained on the 75 µ sieve underwent wet sieving according to IS 2720 (Part 4) guidelines [9]. Preliminary laboratory results classified the soil as well-graded coarse-grained with Cu=15.055 and Cc=1.105, containing minor silt and clay fractions. The Atterberg limits for the 0.425 mm lesser fraction were determined following IS: 2720 (Part 5) standards [10]. Using heavy compaction per IS 2720 (Part-8) [11], the maximum dry density (MDD) and optimum moisture content (OMC) were found to be 2.15 g/cc and 9.6%, respectively. The California bearing ratio (CBR) after 4 days of soaking was 10%, meeting MoRTH specifications [12].

Table 1. Characterization of materials used in pavement sections PS-1 and PS-2

Material	Test / Parameter	Results	Specified limits as per MoRTH guidelines
Subgrade soil	Gravel (< 100 mm > 4.75 mm), %	27.33 C_u=15.055; C_c=1.105	-
	Sand (< 4.75 mm > 0.075 mm), %	60	-
	Silt / Clay (< 0.075 mm), %	12.67	-
	Liquid limit, %	28.8	-
	Plastic limit, %	26	-
	Plasticity index, %	2.80	-
	CBR (4 days soaked condition), %	10	-
Coarse aggregates	Aggregate origin/type	Igneous / Granite	-
	Specific gravity	2.68	-
	Water absorption, %	0.27	2
	Impact value, %	15.23	30
	Crushing value %	18.5	30
	Abrasion value, %	29	35
	Elongation index, %	12.34	35
	Flakiness index, %	9.62	35
	Angularity number	7	-
Fine aggregates	Aggregate Type / Origin	M-sand / Igneous Granite	-
	Specific gravity	2.68	-
	Water absorption, %	1.04	-
	Bulk density, g/cm^3	1.72	-
	Bulking, %	8	-
Bitumen	Binder type	VG-30	-
	Specific gravity	1.01	0.97 to 1.02
	Ductility, cm	76	>40
	Softening point, ^{0}C	49	>47
	Flash & fire point, ^{0}C	302, 316	>220
	Penetration, mm	64.33	>45
Cement	Specific gravity	3.15	3.1 to 3.16
	Normal consistency (%)	28	26 to 35
	Initial setting time (minutes)	40	>30
	Final setting time (minutes)	620	>600
	Fineness	252	>225
	Type / Grade	OPC / 53 Grade	-

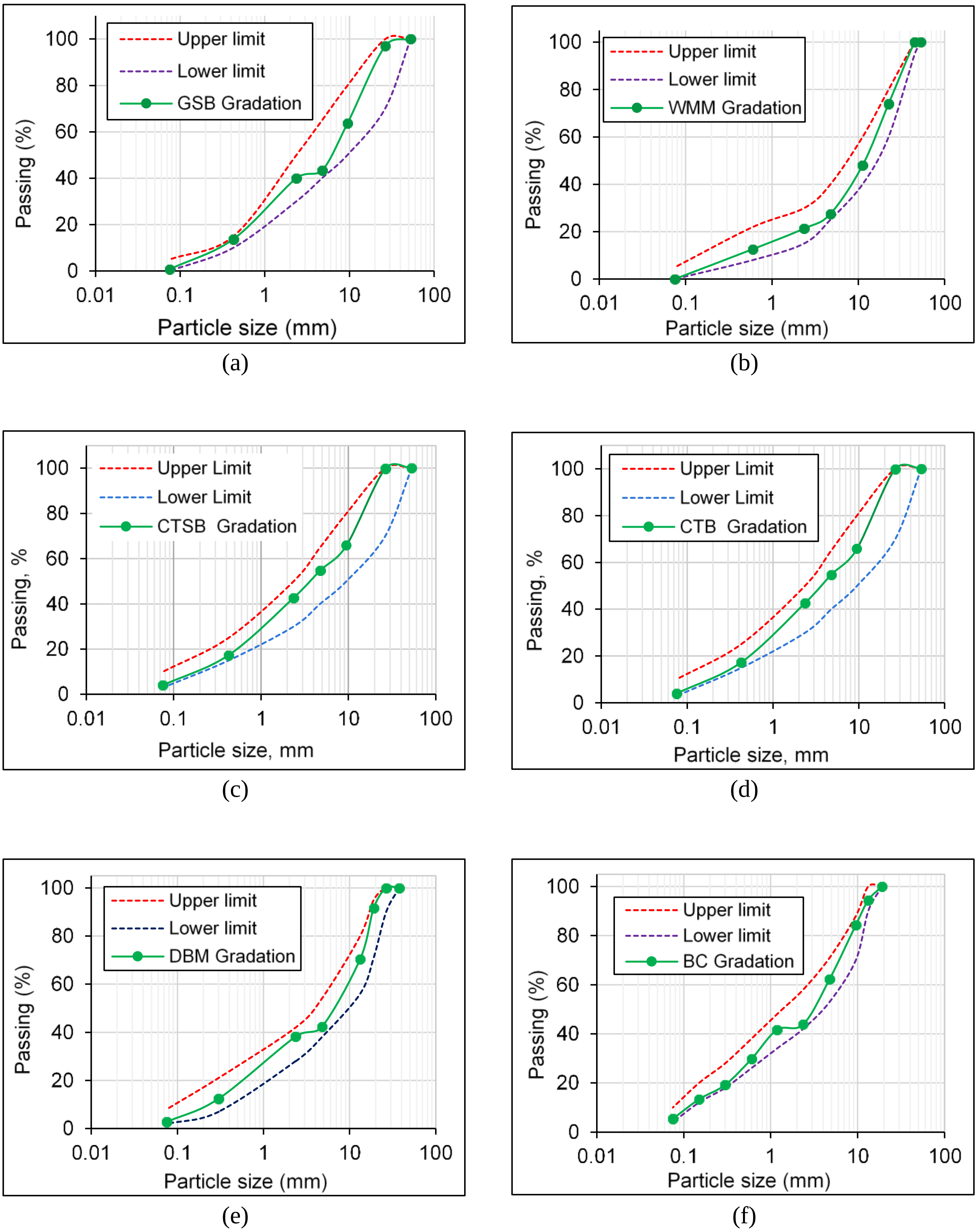

Fig. 1. Aggregate gradation for different layers of flexible pavement used in RCRA for pavement section PS-1 and PS-2 model as per limits specified by MoRTH; (a) GSB Grade II; (b) WMM; (c) CTSB Grade III; (d) CTB Grade III; (e) DBM Grade II; (f) BC Grade II;

The coarse aggregates and fine aggregates (M-Sand) used in the research were procured from a quarry situated in Bidadi, near Bengaluru. These aggregates are geologically categorized as igneous granite. To examine their fundamental properties in accordance with IS 2386 Part I to V, the aggregates were tested for the basic properties and the test results for both coarse and fine aggregates are detailed in **Table 1** [13]. The pavement model, consisting of GSB, WMM base, CTSB, CTB, DBM surface course, and BC wearing course, adhered to MoRTH's aggregate gradation requirements as shown in **Fig. 1**. Using Rothfutch's mix proportioning method, aggregates ranging from 26.5 mm to 0.075 mm were combined to achieve the desired gradation for different pavement layers. In the preparation of CTB specimens, Ordinary Portland cement (OPC) Type I - 53 grade was used. Preliminary tests on the cement were carried out following the guidelines of the Bureau of Indian Standard (BIS) code, and the corresponding test results can be found in **Table 1** [13]. The preliminary examination results for the VG-30 grade binder, following IS - 1203 Indian standard code, were conducted the corresponding results are tabulated in **Table 1** [14].

RCRA description

Fig. 2., depicts the pictorial representation of RCRA. It is a versatile laboratory apparatus designed to replicate the compaction and rutting processes of flexible pavement layers, offering adjustable contact pressures from 0.6 N/mm² to 3 N/mm² using steel-wheeled and rubber-tyred rollers. It incorporates a programmable logical circuit (PLC) and human-machine interface (HMI) connected to transducers for data recording, and it can simulate ambient pavement temperatures during rutting. The RCRA's unique design, featuring a mould measuring 640 mm x 250 mm in cross-section and 1000 mm in depth, sets it apart from other pavement analysers, enabling comprehensive studies on rutting across various pavement layers.

Test specimen and instrumentation

The study selected trial pavement sections based on predefined design parameters, including subgrade CBR, traffic volume, and temperature, limiting the investigation to a pavement thickness suitable for a 50 msa traffic intensity and a 10% CBR subgrade soil. The chosen pavement section PS-1 included layers of GSB (200 mm), WMM (250 mm), and bound layers with DBM (105 mm) and BC (40 mm). Correspondingly, the second pavement section PS-2 included layers of CTSB (200 mm), CTB (140 mm), and bound layers with DBM (60 mm) and BC (40 mm). Each pavement layer was compacted individually using a hydraulic roller compaction method using RCRA. The resulting target densities achieved was 2.15 g/cm^3 for SG, 2.49 g/cm^3 for GSB, 2.38 g/cm^3 for WMM, 2.30 g/cm^3 for CTSB and 2.40 g/cm^3 for CTB within the RCRA mould.

Fig. 2. Roller compactor cum rut analyser

4. Results and discussion

Determination of optimum parameters – moisture, binder, and cement

Various parameters such as the moisture content, binder content and cement content serves as the critical parameters in the construction of different layers of the pavement. It is very important to note that the subgrade, sub-base and base layers of pavement sections are compacted using optimum moisture content so as to attain maximum dry densities after compaction. The layers beneath bituminous bound layers of PS-1 such as the subgrade soil, GSB, and WMM were compacted within RCRA mould by the method of roller compaction using optimum moisture content. Similarly, in case of PS-2 the pavement layers consisting of soil subgrade, CTSB, and CTB were compacted within RCRA mould using optimum moisture content. The OMC for all the pavement layers was determined by the method of heavy compaction method. The MDD achieved was 2.15 g/cm^3 for SG, 2.49 g/cm^3 for GSB, 2.38 g/cm^3 for WMM, 2.30 g/cm^3 for CTSB and 2.40 g/cm^3 for CTB within the RCRA mould as shown in **Fig. 3.**

The current research adopts a three-step approach to ascertain the ideal cement content for CTB and CTSB. Firstly, it employs graded aggregates according to IRC: SP-89 to establish the OMC and MDD for CTSB/CTB across varying cement contents ranging from 2 % to 5 % in 0.5% increments, utilizing the modified compaction test method. Secondly, 150 x 150 x 150 mm cubes were casted using OMC to achieve the previously determined MDD for various cement contents. Subsequently, the compressive strength of these cubes are assessed after a 7-day curing period as detailed in **Table 2**. Lastly, optimal cement content is selected in accordance with the criteria outlined in IRC-37 guidelines. For pavement section PS-2 investigated in this study, the research opts for a cement content of 3% for CTSB layers and 5% for CTB layers.

Table 3 shows mix design parameters for DBM and BC with specified limits as per MoRTH guidelines. Marshall specimens, measuring 101.5 mm in diameter and 63 mm in height, were prepared with varying binder contents. These specimens were compacted using a Marshall compaction rammer to achieve a predetermined density. After 24 hours of air cooling at room temperature and a subsequent water bath immersion of 60-90 minutes at 60°C, the stability and flow properties are measured using a Marshall testing machine. This process is repeated with different binder contents to identify the optimal binder content that ensures sufficient stability and flow. The research utilizes VG-30 grade bitumen for DBM and BC layers, with respective optimum binder contents of 5.0% and 5.4%.

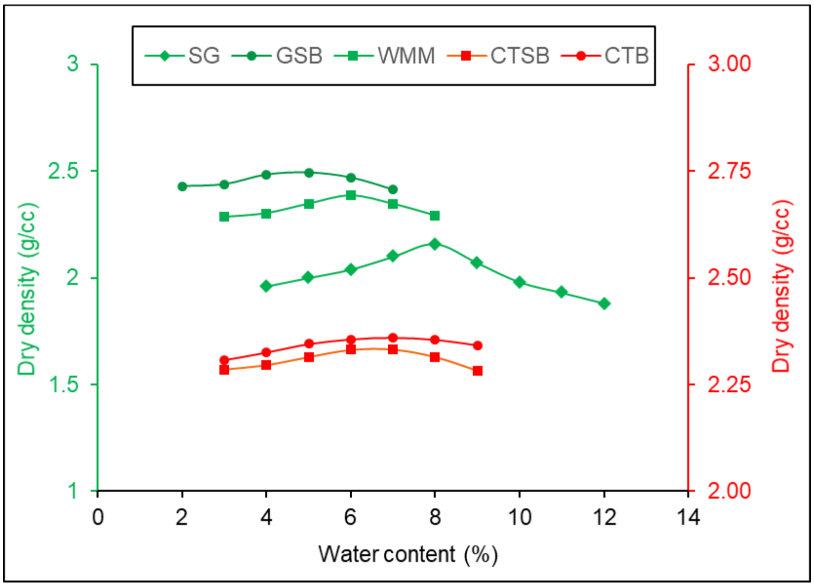

Fig. 3. Determination of OMC and MDD

Table 2. Cube compressive strength of cement stabilized material

Cement content, %	**7 days cube compressive strength of cement stabilized material, MPa**	**Requirements as per IRC-37:2018**
2	1.15	
2.5	1.92	
3	**2.61**	**1.5 to 3 MPa (CTSB)**
3.5	3.72	
4	4.6	
4.5	5.76	
5	**6.84**	**4.5 to 7 MPa (CTB)**

Table 3. Mix design parameters for DBM and BC with specified limits as per MoRTH guidelines

Parameters	Results		Specified limits as per MoRTH
	DBM	BC	
Marshall stability, kg	1117	1358	900 minimum
Marshall flow value, mm	3.30	2.76	2 to 4
Air voids in total mix, %	3.12	3.91	3 to 6
Voids filled with bitumen, %	72.4	74.30	65 to 75
Average bulk density, g/cc	2.315	2.356	-
Design bitumen, % (as per asphalt institute procedure) [15]	**5.0**	**5.4**	-

Rutting of pavement sections using RCRA

RCRA was employed to research on the rutting characteristics of two pavement sections namely, PS-1 and PS-2 as shown in **Fig. 4**. The HMI was employed to input initial data, including the projected rut depth, number of passes, and the chosen operational mode (either compaction or rutting). The rubber-tyred roller was correctly aligned and brought into contact with the surface of the test specimen. To regulate the necessary tire pressure applied by the rubber-tyred wheel on the test specimen, seating loads (steel weights attached to a frame positioned over the roller) were either added or removed. The roller and frame arrangement incorporated a dead load equivalent to 35 kilograms, resulting in a corresponding contact pressure of 5.7 kg/cm² or 0.56 MPa on the rubber tire. The rubber-tyred wheel, along with the seating load frame arrangement, was set to execute a reciprocal motion on the test section. It's worth noting that this testing method accurately represented situations that mimicked single-lane roads accommodating two-way traffic. However, it did not simulate the conditions of one-way traffic lanes characterized by a unidirectional flow.

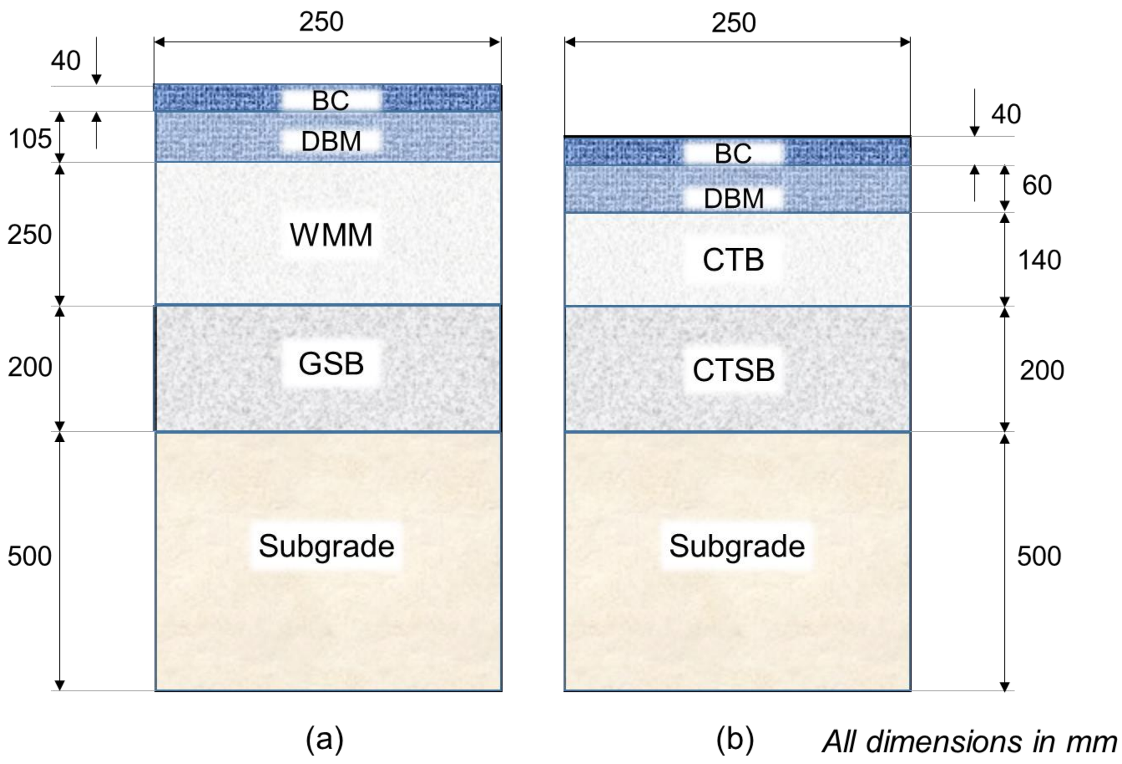

Fig. 4. Pavement sections considered for rutting using RCRA (a) PS-1 with unbound aggregate base layers; (b) PS-2 with cement stabilized aggregate base layers

Fig. 5. RCRA rutting operation in progress

Rutting of PS-1

The pavement section under investigation, PS-1, underwent a rigorous rutting test utilizing the RCRA. This experiment aimed to simulate the real-world stress and wear that road surfaces endure. In the RCRA setup, a rubber wheel attached to a loading frame played a pivotal role in transmitting the load to the test specimen as shown in **Fig. 5.** Throughout the entire rutting procedure, a consistent single wheel load of 35 kilograms and a uniform tire pressure of 5.7 kg/cm² were meticulously maintained. However, for the sake of intensifying pavement damage, the option to adjust the wheel load and tire pressure as necessary was available. The RCRA wheel assembly operated at a frequency of 25 passes per minute while maintaining a speed of 0.75 km/hr. The experiment's termination criteria were defined as either reaching an average rut depth of 20 mm or completing 100,000-wheel load passes, whichever came first. Notably, RCRA had the capability to automatically measure rut depth or the maximum vertical displacement observed within the wheel path, displaying an impressive accuracy of 0.1 mm.

To mitigate the influence of the specimen mould's boundary effects, rut depths were measured along the middle third of the wheel path within the test section. The progression of rut depth with the application of wheel passes on the test segment was visually represented in **Fig. 6**. Initially, rut depth assessments were conducted after every 1000 passes. After the first 10,000 wheel passes, the assessment frequency transitioned to every 10,000 wheel passes, optimizing the efficiency of data collection. The experiment's results were significant, with an R-squared value of 0.9629, indicating a substantial correlation between the number of passes and the resulting rut depth in the laboratory rutting model. This finding underscored the reliability and predictability of the RCRA testing methodology in evaluating the performance of the PS-1 pavement section under simulated conditions, providing valuable insights for pavement design and maintenance.

Rutting of PS-2

The pavement section PS-2, which was constructed with Cement Treated Base (CTB) layers, was subjected to a rigorous rutting study using RCRA. This experiment aimed to replicate the real-world stresses and strains that pavement surfaces endure. In this setup, a rotating rubber wheel attached to a loading frame was the key element responsible for transferring the load to the test specimen housed in the RCRA mould. Maintaining strict adherence to guidelines, a constant single wheel load of 40 kg and a uniform tire pressure of 8 kg/cm² were applied, in line with the requirements specified in the IRC-37:2018 guidelines for pavement sections with CTB layers. The RCRA wheel assembly, responsible for inducing rutting, operated at a speed of 0.75 km/hr, with a frequency of 25 passes per minute. The experiment's stopping criteria were established to reach either an average rut depth of 20 mm or the completion of 100,000-wheel load passes, whichever occurred first. Initially, rut depth assessments were conducted after every 1000 passes. After the initial 10,000 wheel passes, the assessment frequency transitioned to every 10,000 wheel passes, optimizing data collection efficiency. The results of this experiment revealed a substantial correlation between the number of wheel passes and the resultant rut depth, as indicated by an R-squared value of 0.9050. This underlined the robustness of the RCRA testing methodology in evaluating the performance of pavement section PS-2 with CTB layers under simulated conditions, providing critical data for pavement design and maintenance.

Fig. 6., provides a graphical representation of the rutting behaviour of two pavement sections under study, PS-1 and PS-2, constructed with unbound and cement-bound base layers, respectively. This graphical model illustrates the variation in rut depth concerning the number of wheel load repetitions applied using RCRA. In the early stages of a newly constructed flexible pavement subjected to traffic loading, post-compaction rutting occurs due to the reduction of air voids. This phenomenon was observed in the initial 10,000 passes of wheel loads in the RCRA pavement model for both PS-1 and PS-2. Following the post-compaction phase, the rate of rutting gradually decreased, eventually leading to the emergence of plastic shear flow. This phenomenon, which occurs over an extended period, is characterized by shear failure of the bituminous bonded layers without any notable volume change.

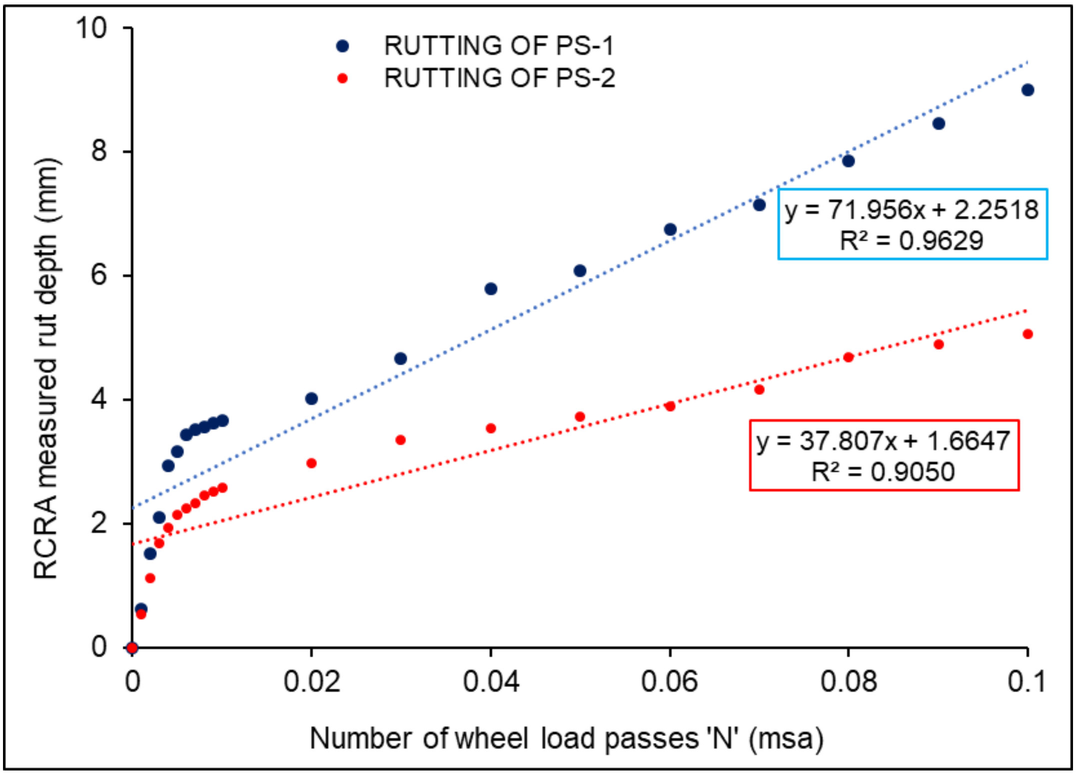

Fig. 6. Correlation between number of wheel load passes v/s rut depth

This specific aspect is a notable feature of the RCRA rutting model, as it closely replicates the actual field behaviour of pavements in service. It's important to emphasize that the cumulative rut damage observed in the RCRA model results from the combined response of all pavement layers, each contributing at different levels. This holistic simulation approach offers invaluable insights into the intricate mechanisms underlying rutting in real-world pavement scenarios, as evidenced by the VESYS rut model [5]. These findings hold significant implications for optimizing pavement design and maintenance strategies, ultimately leading to more durable and safer road infrastructure.

Comparison of rutting response of PS-1 and PS-2

Rutting is a critical concern in the field of pavement engineering, as it directly impacts the durability and performance of roadways. It refers to the permanent deformation or depression of the pavement surface caused by the repeated passage of vehicles over time. This phenomenon not only affects the ride quality for road users but also poses a significant maintenance challenge for transportation authorities. Therefore, the present research aims to delve into the rutting phenomenon within the context of pavement models that encompass both bound and unbound base layers within the RCRA mould. The research focuses on two specific pavement sections, namely PS-1 and PS-2, to draw insights into the rutting behaviour associated with unbound and cement-bound aggregate bases, respectively. The comparison begins with an examination of PS-2, which incorporates cement-bound aggregate base layers. These layers are meticulously designed by blending cement with graded aggregate material in adherence to the guidelines specified by the Indian Roads Congress (IRC). This meticulous approach results in the creation of a stable and highly durable base and sub-base layer. The binding action of cement significantly bolsters the structural integrity of the pavement, rendering it more resilient in the face of the stresses and deformations inflicted by vehicular traffic.

Cement stabilization plays a pivotal role in enhancing the load-bearing capacity of the Cement Treated Base (CTB) layer. This characteristic makes pavements with cement-bound bases capable of supporting heavier traffic loads without succumbing to excessive deformation or rutting. The even distribution of applied loads across the pavement structure minimizes localized stress and strain, a pivotal factor in the prevention of rut formation. Moreover, the cement's binding action fosters cohesion among aggregate particles, reducing the propensity for deformation and rutting under the repeated application of wheel loads. As a result, the pavement surface remains stable and resistant to rutting, as evidenced in **Fig. 6.**

On the contrary, the conventional flexible pavement section, PS-1, relies on unbound aggregate base layers without any cement or binding agents. These layers rely on the friction and interlock between the aggregate particles to provide support. While they can offer some structural support, they are generally less stable and more susceptible to deformation and rutting under the influence of traffic loads. Unbound layers typically exhibit a lower load-bearing capacity when compared to their cement-bound counterparts, rendering them more prone to rutting over a given number of wheel load repetitions.

The absence of a binding agent in unbound layers exposes the aggregate particles to distortion, leading to deformation and rutting when subjected to traffic loads. Uneven load distribution can result from the inherent lack of cohesion in unbound layers, leading to concentrated stress points and an increased susceptibility to rutting. Although unbound layers can perform acceptably under certain conditions, they often necessitate more frequent maintenance and rehabilitation to rectify rutting and deformation issues.

5. Conclusions

This study examined two pavement sections: one represented a traditional flexible pavement (PS-1), while the other used a semi-rigid pavement design with cement-stabilized intermediate layers (PS-2). The selection of these models was based on IRC-37:2018 guidelines and design factors like CBR and traffic intensity. The graphical representation in the study depicted the rut depth variation as the number of wheel load repetitions increased, using the RCRA model. It revealed post-compaction rutting in the initial 10,000 wheel passes and the subsequent transition to plastic shear flow. This RCRA model closely mimics real-world pavement behaviour, offering insights into how different pavement layers collectively impact rutting damage. The research concluded that PS-2, with cement-bound aggregate bases, demonstrated superior performance in resisting rutting due to its enhanced structural integrity, increased load-bearing capacity, even load distribution, and resistance to deformation under traffic loads. In contrast, PS-1, with unbound aggregate bases, proved more susceptible to rutting and deformation. This highlights the advantages of using cement stabilization to enhance the overall durability and longevity of flexible pavements. The study's findings provide valuable insights for pavement engineering and the construction of resilient and long-lasting road infrastructure.

In light of these findings, it is evident that the RCRA pavement rutting model underscores the superiority of pavement sections with cement-bound aggregate bases over those relying on unbound aggregates. The former exhibits enhanced stability, load-bearing capacity, and resistance to rutting, making it a more durable and cost-effective choice for roadway construction. This research contributes valuable insights for the field of pavement engineering, helping transportation authorities to make informed decisions that promote long-lasting and reliable road infrastructure.

References

[1] S. Hussan, M. A. Kamal, I. Hafeez, and N. Ahmad, ‘Comparing and correlating various laboratory rutting performance tests’, *International Journal of Pavement Engineering*, vol. 20, no. 10, pp. 1239–1249, 2019.

[2] G. Al-Khateeb and I. Basheer, ‘A three-stage rutting model utilising rutting performance data from the Hamburg Wheel-Tracking Device (WTD)’, *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice*, vol. 18, no. 3, pp. 12–25, 2009.

[3] M. Witczak, ‘Simple Performance Tests: Summary of Recommended Methods and Database.’, 2006.

[4] L. F. Walubita, L. Fuentes, S. I. Lee, I. Dawd, and E. Mahmoud, 'Comparative evaluation of five HMA rutting-related laboratory test methods relative to field performance data: DM, FN, RLPD, SPST, and HWTT', *Construction and Building Materials*, vol. 215, pp. 737–753, 2019.

[5] H. K. Salama, K. Chatti, and S. W. Haider, 'Backcalculation of permanent deformation parameters using time series rut data from in-service pavements', *Transportation research record*, vol. 1949, no. 1, pp. 98–109, 2006.

[6] Smith T Jolly R, 'Concrete Pavement a Sustainable Choice', *Proceedings of the 8th International Conference on Concrete Pavements, Colorado Springs, CO: International Society for Concrete Pavements,* pp. 585-606..

[7] P. Kumar and S. Shukla, 'Flexible pavement construction using different waste materials: A review', *Materials Today: Proceedings*, 2022.

[8] A. Francois, A. Ali, and Y. Mehta, 'Evaluating the impact of different types of stabilised bases on the overall performance of flexible pavements', *International Journal of Pavement Engineering*, vol. 20, no. 8, pp. 938–946, 2019.

[9] IS: 2720 (Part 4), 'Method of test for soils: determination of grain size distribution', *Bureau of Indian Standards*, 1985.

[10] 'IS : 2720 (Part 5) - 1985 Indian Standard Methods of Test for Soils Part 5 Determination of Liquid and Plastic Limit'.

[11] 'IS-2720 (Part-8):1983 (Reaffirmed- May 2015) "Methods of test for soils: Determination of water content - dry density relation using heavy compaction"'.

[12] B. MoRT&H, *Ministry of Road Transport & Highways*. Indian Roads Congress New Delhi, India, 2013.

[13] IS 2386–Part, *IS 2386: Methods of test for aggregates for concrete, Part I*. 1963, pp. 11–4.

[14] 'IS 1201 to IS 1220 : 1978 'Methods for testing tar and bituminous materials (first revision)'.

[15] Asphalt Institute, *Mix design methods for asphalt concrete and other hot-mix types*, no. 2. Asphalt Institute, 1997.