DOI: 10.29327/1430212.49-107

26º Encontro Nacional de Conservação Rodoviária (ENACOR)
49ª Reunião Anual de Pavimentação (RAPv)

GLASS FIBRE GRID REINFORCED BITUMINOUS PAVEMENTS – FIELD STUDY

Abhijith B.S[1]; Stepan Bohus[2]; Kavitha G[3]; Atul Narayan S P[4] & Veeraragavan A[5]

RESUMO

O trincamento de superfícies betuminosas é um problema comum observado na maioria das estradas em todo o mundo. Quando uma nova camada betuminosa é aplicada sem solucionar as trincas na superfície betuminosa existente, as tensões de cisalhamento e de tração geradas pelas cargas de tráfego ou gradientes de temperatura podem resultar na propagação de trincas para a superfície de uma nova camada. O uso de soluções de reforço intercamadas, como grades de fibra de vidro, que fornecem maior resistência à tração em uma menor tensão de tração, provou ser eficaz em termos de retardar a propagação de trincas através de vários testes laboratoriais. O presente estudo centra-se na corroboração de resultados laboratoriais através da avaliação do desempenho em campo de seções reforçadas com grade de fibra de vidro ao longo de um período de tempo. O desempenho relativo de revestimentos de mistura asfáltica em trechos de estradas de um projeto de Rodovia Nacional da Índia com e sem grades de fibra de vidro foi estudado ao longo de dois anos, por meio de avaliação periódica do desempenho das condições estruturais e funcionais. A abordagem de aprendizado de máquina foi usada para classificar e agrupar diferentes seções com e sem grades de fibra de vidro para identificar e agrupar as seções com base no desempenho. As descobertas desta pesquisa são um aspecto integrante da consideração do reforço da grade de fibra de vidro do ponto de vista da manutenção do pavimento.

PALAVRAS-CHAVE: Grades de fibra de vidro; resistência à trincas; análise da bacia de deflexão; técnica de agrupamento.

ABSTRACT

Cracking of bituminous surfaces is a common distress seen in the majority of roads across the world. When a new bituminous overlay is provided without addressing the cracks in the existing bituminous surface, shear and tensile stresses generated by traffic loads or temperature gradients can result in the propagation of cracks to the surface of a new layer. Using interlayer reinforcement solutions such as glass fibre grids, which provide higher tensile strength at lower tensile strain, has proven to be effective in terms of delaying crack propagation through various laboratory investigations. The current study focuses on corroborating laboratory results through field performance evaluation of glass fibre grid-reinforced sections over a period of time. The relative performance of asphalt mixture overlays on an Indian National Highway project road sections with and without glass fibre grids was studied over an year, through periodic structural and functional condition performance evaluation. Machine Learning Approach was used to rank and cluster different sections with and without glass fibre grids to identify and group the sections based on performance. The findings from this investigation are an integral aspect of the consideration of glass fibre grid reinforcement from the pavement maintenance point of view.

KEY WORDS: Glass fibre grids; cracking resistance; deflection bowl analysis; Clustering technique.

[1,2] **Saint-Gobain Adfors, Abhijith.BS@saint-gobain.com ; Stepan.bohus@saint-gobain.com ,**
[3] **RASTA Center for Road Technology, India, gkavitha@rastaindia.com**
[4,5] **Indian Institute of Technology Madras, India, atulnryn@iitm.ac.in ; aveeraragavan@gmail.com**

INTRODUCTION

The occurrence of bituminous surface cracks remains a significant concern on roads across the world. These cracks are classified into various types based on their frequency and severity. Timely crack sealing is imperative to prevent their further expansion. Notably, Glass fibre grid interlayer has demonstrated remarkable effectiveness as a crack retarder when placed between existing damaged bituminous pavement and the bituminous mixture overlay (Nguyen et al., 2013; Graziani et al., 2014). Glass fiber has Young's modulus of approximately 70 GPa, which is almost 20 times higher than typical asphalt concrete modulus at around 20°C, and high tensile strength (Darling and Woolstencroft, 2004).

Glass fiber grids possess the capability to achieve high tensile strength at low deformations, significantly enhancing the fatigue performance of bituminous pavements (Asphalt Academy, 2022). The use of glass fiber grids is not uncommon and has been recognized as a viable option for reinforcing bituminous layers in many counties (Roy, S. and Dixit, M., 2019; Nithin, S., Rajagopal, K. and Veeraragavan, A., 2015). Various mechanisms have been proposed in the literature highlighting how glass fiber grids benefit bituminous pavements (Lytton 1989; Dhakal, N., Elseifi, M.A. and Zhang 2016). The reinforcement mechanism is evident when the glass fibre grid material exhibits a higher modulus than the overlay. In reinforcement, cracks initiated from the old pavement are observed to reach the grid interface and propagate horizontally beneath it until the fracture energy dissipates. Additionally, Safavizahdeh et al. (2015) describe a strain-relieving mechanism where cracks from the existing pavement propagate vertically and come to a halt at the bottom of the grid interface. Subsequent application of repeated loads initiates cracks on the upper portion of the grid interface, which then spread through the overlay.

Numerous laboratory investigations have been conducted on glass fiber grid-reinforced bituminous mixtures, showcasing the performance of this system (Arsenie et al., 2017; Safavizadeh, S.A., Cho, S.H. and Kim, Y.R., 2022; Abhijith et al., 2023). Fatigue of bituminous mixtures reinforced with glass fibre grids are usually evaluated in the laboratory with four-point bending fatigue tests. These fatigue tests are conducted at multiple strain levels with different loading waveforms - sinusoidal and haversine. The fatigue life of glass fibre grid-reinforced mixtures was found to be at least three times higher, specifically when the mixtures were subjected to higher strain levels. Furthermore, the experimental investigation carried out on glass fibre grid inlaid bituminous mixtures by Canestrari et al., (2015) has shown that geogrid reinforcement does not noticeably influence the flexural stiffness and strength in the pre-cracking phase, whereas the crack propagation speed can be significantly reduced and the failure behavior may change from quasibrittle to ductile, depending on the interlayer shear resistance. These laboratory results were corraborated by periodic visual observation of field performance in terms of reflective cracking evolution. Bohus S., Pavel, S. and Jan, K., (2023) show interlayer bond strength between bituminous mixtures and glass fibre grid to depend mainly on tack coat type and the solid bitumen content in the emulsion being used.

Nguyen et al., (2013) conducted full-scale tests on grid-reinforced pavements at the IFSTTAR APT facility. The conclusions from this study has enhanced the understanding of grid-inlaid bituminous mixtures. The tests on pavement structures with and without grids have verified that placing a glass fiber grid near the bottom of the bituminous layer markedly enhances fatigue life, provided a strong bonding with the bituminous layer is achieved. While there are good amount of works carried out to prove the efficiency of glass fibre grids in reinforcing bituminous mixtures, it will be interesting to monitor and assess the performance of grid-inlaid sections under mixed traffic and environmental conditions from a real field perspective. This study focuses on the functional and structural evaluation of glass fibre grid-reinforced sections from a National Highway section in India.

MATERIALS AND METHODS

The study is confined to the performance evaluation of the pavement sections constructed with and without a glass fibre grid for a period of one year (three cycles)covering all the seasons. The data collection methodology covers different environmental conditions to which the pavement with glass fibre grids are subjected to and compares the relative performance through structural and functional evaluation studies. This National Highway project (NH 75) for four laning of the 77.228 km stretch between Devihalli and Hassan in Karnataka, India, has been executed by Devihalli Hassan Tollway Private Limited (DHTPL), on Design, Built, Finance, Operate, and Transfer (DBFOT) basis. The project corridor stretches from Devihalli village in Karnataka, India at Km 108.456 and traverses towards the West, connecting Hirisave, Channarayapatna, and Shantigrama and ends at Hassan district in Karnataka at Chainage 186.684 Km (Approximately 77.228 Km). The map of the road is shown in Figure 1. The commercial operations commenced on the project road in November 2013. The concession period for the project is 30 years.

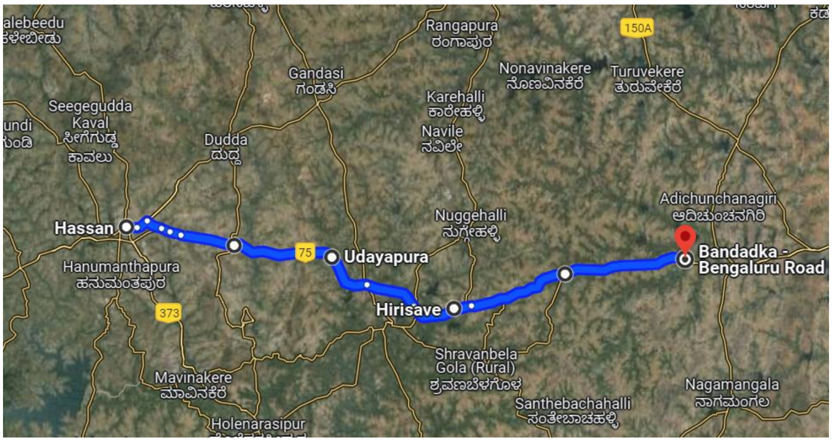


Figure 1. Map of project corridor

Glass fibre grids were used in chosen sections along this highway as part of a rehabilitation strategy in 2018. Glass fibre grids were used on sections where severe alligator cracks were observed, as shown in Figure 2. First, the existing top wearing course layer, Bituminous concrete (BC), was milled. After milling operation, Glass fibre grids was laid on surfaces that had extensive cracks and overlaid with new BC layer. At places where the surface had no distresses after milling, conventional BC overlay was placed without the application of Glass fibre grids. Hence the condition of the pavement before the application of bituminous mixture overlay was different for both the conventional and Glass fibre grids sections. Figure 3 shows the application of CGL on milled surface.

Figure 2. Alligator cracks on wearing course before the application of CGL

Figure 3. Application of CGL on milled surface

The composite glass fibre grid supplied by Saint Gobain Adfors, referred to as CGL, was evaluated and reported. These grids have a peak tensile strength of 115 × 115 ± 15 kN/m at a tensile elongation value of 2.5 ± 0.5 % in both warp and weft directions. The glass fibre grids are coated with an elastomeric polymer with a melting point of coating to be higher than 230°C. The coating is reported to protect the glass fibre grid from damage during installation by Orešković et al. (2019). Technical characteristics of CGL are shown in Table 1.

Table 1. Technical characteristics of GlasGrid™ CGL

Asphalt reinforcement specification (Composite GlasGrid CG100L)			
Grid coating	Thermal stable elastomeric polymer		
Melting point of grid protective coating	≥ 250	˚C	ASTM D276/EN ISO 3146
Melting point of Glass	≥ 820	˚C	ASTM C338
Tensile strength (MD × CMD)	≥ 100 × 100	kN/m	ASTM D6637/EN ISO 10319
Tensile Elongation Ultimate	2.5 ± 0.5	%	ASTM D6637/EN ISO 10319
Tensile Resistance at 2% strain (MD × CMD)	≥ 95 × 95	kN/m	ASTM D6637/EN ISO 10319
Young's modulus	73000	MPa	

26º Enacor
49ª RAPv
Encontro Nacional de Conservação Rodoviária e Reunião Anual de Pavimentação
Aracaju / Sergipe | 19 a 22 ago 2024

Mass per unit area	≥ 535	g/m2	ASTM D5261/EN ISO 9864
Installation nonwoven backing (weight)	≥ 35	g/m2	EN ISO 9864
Installation nonwoven backing (dynamic perforation)	≥ 30	mm	EN ISO 13433
Residual strength after installation damage test	≥ 80	%	EN ISO 10722
Maximum junction strength	≥ 50	N	EN ISO 13426-2/ASTM D 7737
Note: MD – Machine direction ; CMD – Cross Machine direction			

The objective of the study is to understand the effectiveness of crack sealing technology with CGL at different time intervals in an in-service highway pavement.

The first cycle of data collection corresponding to functional and structural conditions was started in December 2021. The second and third cycle of data collection was completed within a span of 1 year. The data collection includes roughness measurements, the percentage area of distresses such as cracking and rutting, deflection bowl, and extracted bituminous core sample analysis.

PAVEMENT FUNCTIONAL AND STRUCTURAL CONDITION

Alligator Cracks

The density of alligator cracking along the project road overlaid with bituminous concrete and GlasGrid™ CGL was compared with the conventional section, as shown in Figure 4. The mean value of the extent of alligator cracks was observed to be relatively lower in the case of sections overlaid with Bituminous Concrete + GlasGrid™ CGL in comparison to conventional sections. It is noted that after three study cycles, it was found that the GlasGrid™ section CGL section (applied to a severely cracked surface), had 2.49% cracking on average, while the conventional section had 5.55% cracking (no initial cracks). Without GlasGrid™ CGL, cracks would have propagated faster, leading to significantly higher crack percentages than in the GlasGrid sections. This appears to indicate the effectiveness of the use of GlasGrid™ CGL in retarding distress.

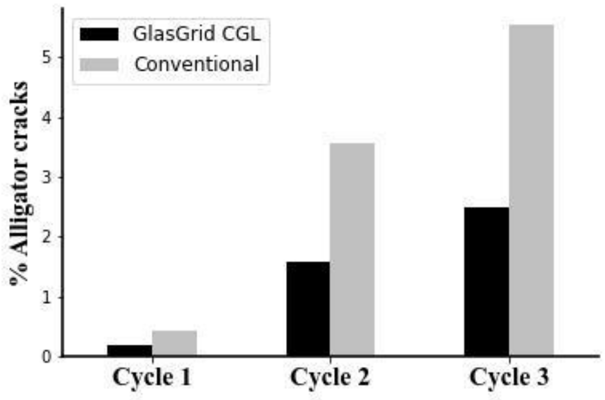


Figure 4. The evolution of alligator cracks over a period of time for GlasGrid™ CGL and conventional section

Crack Investigation on Extracted Cores

During the third cycle of the study, cores were extracted to observe the crack pattern. The investigation aimed to analyze the crack patterns and assess the effectiveness of the CGL interlayer in preventing the propagation of cracks. Cores were extracted from cracked locations of both CGL and conventional road sections for a detailed examination of crack propagation patterns. Figure 5 and Figure 6 show the crack propagation patterns in extracted cores. On observing the crack patterns, it is evident that the GlasGrid^{TM} CGL interlayer demonstrates effectiveness in arresting bottom-up crack propagation. The cracks observed in CGL interlayer sections were also top-down cracks, which can appear due to the age hardening of the wearing course material. In contrast, the cracks observed in the conventional sections have propagated either from the binder course to the wearing course layer or vice versa i.e. the top-down cracking from the surface has reached the bottom of the bituminous layers and the bottom-up cracking has reached the surface.

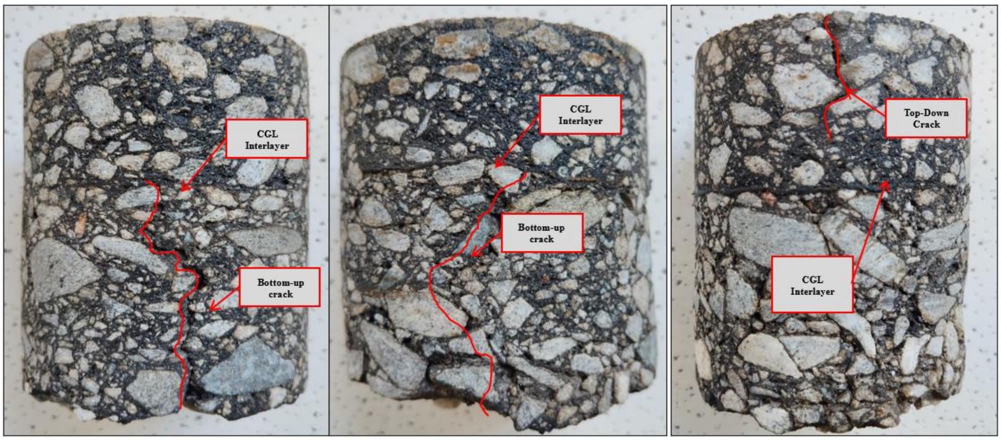


Figure 5. Retardation of crack growth due to GlasGrid^{TM} CGL interlayer

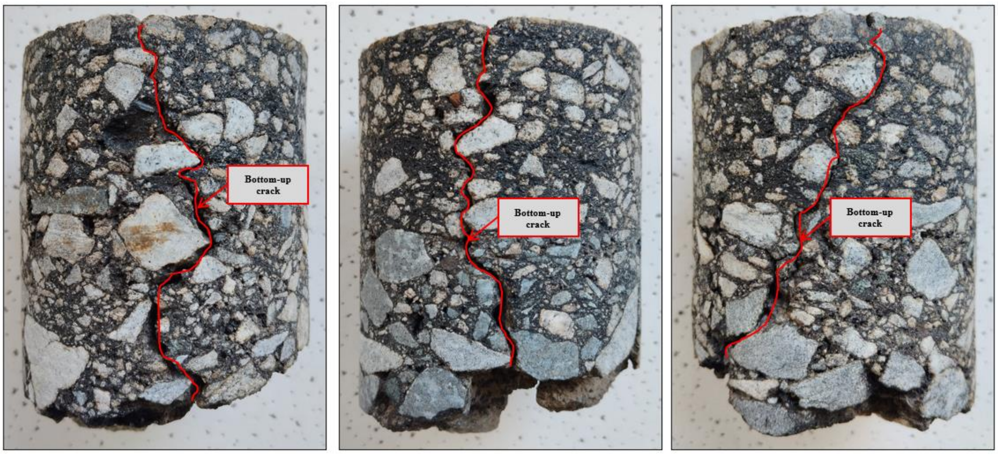
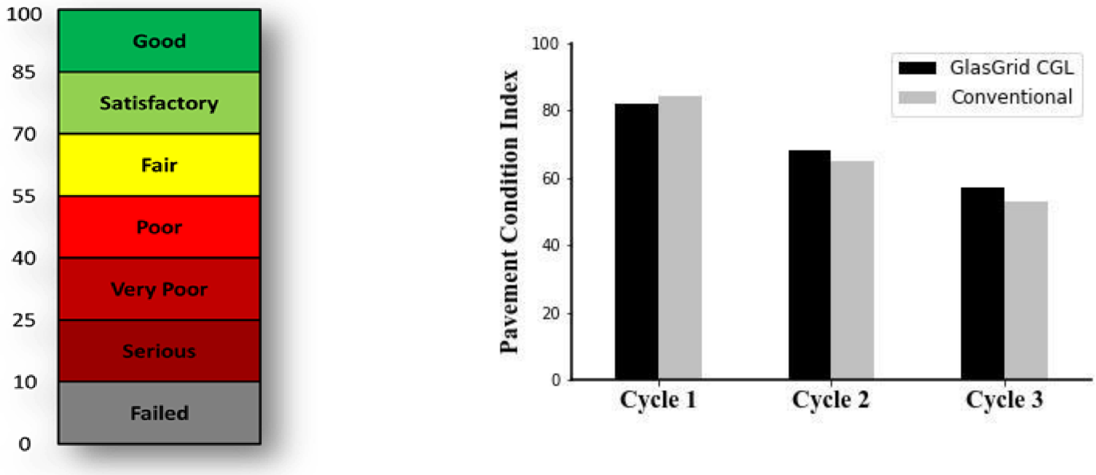


Figure 6. Crack propagation pattern in conventional pavements without reinforcement

Pavement Condition Index (PCI)

The pavement condition index is a numerical value given, based on the assessment of the road condition visually. PCI is calculated for the prediction of performance and suggests necessary maintenance or rehabilitation measures to treat the existing surface defects. It is a standard measure that describes the current situation of the road. For calculating PCI, the procedure mentioned in ASTM D6433-20 is followed. In the present study, condition indices for different road stretches are calculated. PCI numerical values range from 0 to 100, 0 being failed and 100 being good condition.



(a) PCI rating scale **(b) PCI across 3 cycles**

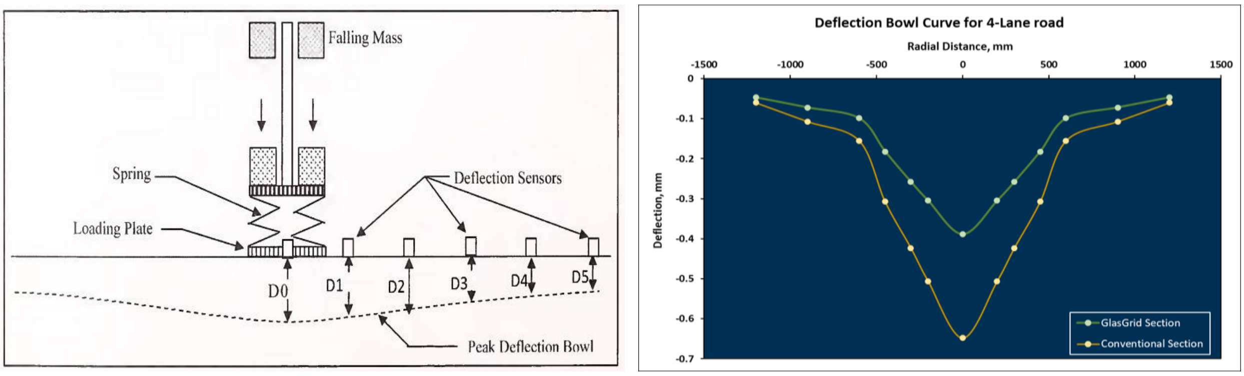
Figure 7. Pavement condition index for GlasGrid™ CGL and unreinforced section.

Figure 7a shows the standard PCI rating scale, and Figure 7b shows the comparison of PCI values observed across 3 cycles for both the GlasGrid™ CGL sections and conventional sections. The mean PCI values indicate that the GlasGrid™ CGL section consistently shows higher values across all three cycles compared to the Conventional section. Both sections exhibit a decreasing trend in mean PCI values over time, suggesting degradation of pavement condition. However, the important point to be noted is that if there were no GlasGrid™ CGL interlayer, PCI would have decreased at a much faster rate at those sections where GlasGrid™ CGL is currently placed. This is because GlasGrid™ CGL is placed on sections where severe alligator cracks were observed. With the inclusion of GlasGrid™ CGL in these severely cracked sections, PCI has decreased at a lower rate due to the reinforcement effect.

Deflection Bowl Study

Dynamic load that simulates closely the duration and amplitude of load pulses produced by moving wheel load was applied to the conventional pavement sections and GlasGrid CGL interlayer sections during the first cycle of data collection. A falling weight deflectometer (FWD) was used to apply a peak load of 40 kN, which corresponds to the load on one dual wheel set of an 80 kN

standard axle load. The duration of an impulse load remains roughly equivalent to the time it takes to cross the length of a tyre imprint at a speed of around 60 km/h, falling within the span of 20 to 30 ms.
Figure 8a shows the working principle of FWD. Surface deflections are measured at different radial locations. Figure 8b shows an example of the shape of the deflection bowl observed between conventional and GlasGrid^{TM} CGL section. The peak deflections are found to be much higher for conventional sections in comparison to GlasGrid^{TM} CGL sections indicating good structural health of the pavement when reinforcement is used.



(a) Working principle of FWD (IRC:115-2014) **(b) Deflection bowl**

Figure 8. Falling weight deflectometer test carried out on GlasGrid^{TM} CGL and unreinforced section.

The deflections measured from the FWD test are used to plot the deflection bowl basin and some characteristic features of the deflection bowl basin are determined which can be correlated to pavement structural condition and deterioration. The following Deflection bowl parameters have been determined:

- D0 – Maximum Deflection measured at the center of the loading plate of 300 mm diameter.
- SCI – Surface Curvature Index = Δ_0-Δ_r, where Δ_0 – max deflection and Δ_r - deflection are measured at a distance of 500 mm from the point of application of load.
- BCI - Base Curvature Index = Δ_2-Δ_3, where Δ_2 = deflection at a distance of 610 mm and Δ_3= deflection at a distance of 915 mm from the point of application of load.
- BDI – Base Damage Index = Δ_1-Δ_2, Where Δ_1 = deflection at 305 mm, Δ_2 = deflection at a distance of 915 mm from the point of application of load.
- Slope of deflection bowl – It is the slope of the line joining the point of maximum deflection to the point of inflexion of the deflection bowl.

Table 2 provides the summary of deflection bowl characteristics observed between conventional and GlasGrid^{TM} CGL sections. All the indices were observed to indicate the efficiency of the GlasGridTM CGL section to contribute towards the enhancement of pavement load-carrying capacity. The peak deflections indicate that the deflections are reduced by up to 13% in comparison to conventional sections. However, if the conventional sections also had severe cracks like GlasGrid sections, the difference in deflections could have been much higher

Table 2. Summary of deflection bowl characteristics

Type of Pavement	Deflection Bowl Parameter	Mean	Standard Deviation
Saint-Gobain GlasGrid sections	D_0	0.43	0.10
	SCI	0.15	0.05
	BDI	0.17	0.04
	BCI	0.03	0.01
	Slope	0.03	0.01
Conventional sections	D_0	0.49	0.21
	SCI	0.17	0.08
	BDI	0.21	0.10
	BCI	0.03	0.01
	Slope	0.04	0.02

DATA GROUPING USING CLUSTERING TECHNIQUES

Clustering is a popular technique in the field of data analysis that aims to identify inherent patterns and groupings within a dataset. It is particularly useful when dealing with large datasets or when the underlying structure of the data is not explicitly known. The K-means clustering algorithm is one of the commonly used methods for partitioning data into clusters. In K-means clustering, the algorithm iteratively assigns data points to clusters based on their proximity to cluster centroids, which are the mean values of the data points within each cluster. The number of clusters, referred to as K, is predetermined. The algorithm aims to minimize the within-cluster sum of squares, seeking to create clusters with high similarity among their constituent data points and low similarity between different clusters. The output of the K-means clustering process is a set of K clusters, where each data point is assigned to a specific cluster based on its similarity to the cluster centroid. This allows for the exploration and understanding of inherent groupings within the data. The clustering exercise was performed using the K-means method on the obtained field data of both GlasGrid™ CGL and Conventional sections. The goal was to group sections based on their performance in terms of remaining modulus of bituminous layer (E_{bit}), pavement condition index (PCI) and roughness index obtained from the field study. The analysis was conducted using **RStudio 2023.03.0 Build 386 software**. The analysis resulted in the identification of 2 as the optimum number of clusters. This means that the sections were divided into two distinct groups based on their similarities in the aforementioned parameters. A cluster diagram for the analyzed data is represented below in Figure 9.

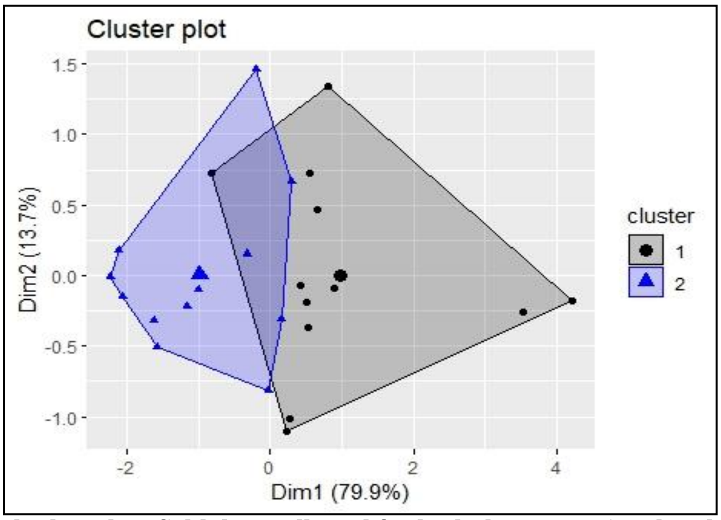


Figure 9. Cluster plot based on field data collected for both the conventional and GlasGrid^{TM} CGL sections

Table 3. Summary statistics of the cluster

Summary statistics for cluster 1:			
	E_{bit}	**PCI**	**Roughness**
Min	450	52	1094
1st Quartile	965.2	78	1364
Median	1184	81.5	1584
Mean	1127.2	79	1611
3rd Quartile	1297.5	85	1746
Max	1666	99	2315

Summary statistics for cluster 2:			
	E_{bit}	**PCI**	**Roughness**
Min	1188	72	830
1st Quartile	1594	81.25	945
Median	1826	89	1147
Mean	1748	89	1129.7
3rd Quartile	1923	99	1206
Max	2047	99	1599

From Table 3, it is clearly seen that Cluster 2 demarcates itself in terms of higher mean values of Ebit and PCI and lower values of Roughness, which in turn connotes the most favourable performance. This cluster contained 12 sections. On the other hand, Cluster 1 exhibited relatively lower mean values of E_{bit} and PCI and higher Roughness, indicating less favourable performance. This cluster also included 12 sections. Interestingly, the analysis revealed that Cluster 2, the most favourable cluster, consisted of 83% GlasGrid^{TM} CGL sections and only 17% Conventional sections. This highlights a clear dominance of GlasGrid^{TM} CGL sections in terms of higher performance.

CONCLUSION

It is to be noted that the surface condition of the pavement before the application of bituminous mixture overlay was different for both the conventional and GlasGrid^{TM} CGL sections. First, the existing top wearing course layer was milled, and the GlasGrid^{TM} CGL was laid on surfaces that had extensive cracks and overlaid with the 50 mm thick wearing course layer. However, at places where the surface had no distresses after milling, conventional wearing course overlay was placed without the application of grid interlayer. For instance, after three study cycles, it was found that the

GlasGrid™ CGL section (applied to a severely cracked surface), had 2.49% cracking on an average, while the conventional section had 5.55% cracking (no initial cracks). Without GlasGrid™ CGL, cracks would have propagated faster, leading to significantly higher crack percentages in the GlasGrid sections. Hence, the performance results between GlasGrid™ CGL and conventional sections in this article should not be directly compared due to differing initial conditions before the application of conventional wearing course overlay versus GlasGrid™ CGL + wearing course overlay. Following are some of the important conclusions from the investigation:

- The study findings demonstrate that the GlasGrid™ CGL interlayer effectively arrests the propagation of cracks and acts as an efficient crack relief layer. Core samples taken from the site reveal the crack propagation pattern in both conventional sections and GlasGrid™ CGL sections. Without reinforcement interlayers, cracks from the lower layer propagate to the surface at a faster rate, consequently reducing the lifespan of the overlay. After 4 years from the time of application of GlasGrid™ CGL, predominant bottom-up cracks were observed in conventional sections while GlasGrid™ CGL has prevented the growth of cracks from the bottom bituminous layer to the overlay effectively.
- The mean PCI values calculated as per ASTM D6433 indicate that the GlasGrid section consistently shows higher values across all three cycles compared to the Conventional section. For instance, the PCI value for GlasGrid™ CGL sections decreased by 16% from the second cycle of data collection to the third cycle, while the PCI reduced by 18% for conventional sections. The point to be noted is despite better initial conditions with low to minimal cracks before the overlay, PCI for conventional sections is decreasing at a faster rate in comparison to GlasGrid sections. This highlights the influence of the crack retarding ability of GlasGrid™ CGL.
- The shape of the deflection bowl and the deflection bowl parameters suggest that the GlasGrid™ CGL sections exhibit better structural strength / load-carrying capacity compared to the conventional sections. Peak deflections were found to be as high as 13% for the conventional sections in comparison to GlasGrid™ CGL sections. However, there cannot be a direct comparison between conventional and GlasGrid™ CGL sections due to initial differing conditions on which the bituminous overlay work was carried out. If the conventional sections had similar severity of cracks like GlasGrid™ CGL sections, the difference in deflection % would have been much higher than the current observation of 13%.
- Clustering using K-means unsupervised machine learning algorithm confirmed the dominance of GlasGridTM CGL sections with 83% in favourable performance cluster (lower roughness index, higher remaining modulus of bituminous layers, and higher pavement condition index), while Conventional sections had only 17% in the cluster.

In summary, the study results affirm the effectiveness of the GlasGrid™ CGL interlayer in enhancing pavement performance by reducing distresses such as cracks and improving both pavement condition index and structural capacity.

REFERENCES

1. Abhijith, B.S., Raj, A., Varma, R., Ayyar, P. and Krishnan, J.M., 2023. Influence of glass fibre grid and its placement on the fatigue damage of asphalt mixture. Materials and Structures, 56(7), p.140.
2. ASTM D6433 (2020). Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. ASTM International, West Conshohocken
3. Bohus, S., Pavel, Sperka. and Jan, Kudrna., 2023. Investigations on shear bond characteristics of grid reinforced asphalt concrete. XXVIIth World Road Congress, Prague (Czech Republic).
4. Arsenie, I.M., Chazallon, C., Duchez, J.L. and Hornych, P., 2017. Laboratory characterisation of the fatigue behaviour of a glass fibre grid-reinforced asphalt concrete using 4PB tests. Road Materials and Pavement Design, 18(1), pp.168-180.
5. Asphalt Academy (2022) Technical guidelines for road construction (TG3), 3rd edn. South African Bitumen Association (Sabita), South Africa.
6. Canestrari, F., Belogi, L., Ferrotti, G. and Graziani, A., 2015. Shear and flexural characterization of grid-reinforced asphalt pavements and relation with field distress evolution. Materials and Structures, 48, pp.959-975.
7. Darling, J.R. and Woolstencroft, J.H., 2004, May. A study of fiber glass pavement reinforcement used in different climatic zones and their effectiveness in retarding reflective cracking in asphalt overlays. In Cracking in Pavements: Mitigation, Risk Assessment and Prevention, Proceedings the 5th International RILEM Conference, Limoges, France (pp. 5-8).
8. Dhakal, N., Elseifi, M.A. and Zhang, Z., 2016. Mitigation strategies for reflection cracking in rehabilitated pavements–A synthesis. International Journal of Pavement Research and Technology, 9(3), pp.228-239.
9. Graziani, A., Pasquini, E., Ferrotti, G., Virgili, A. and Canestrari, F., 2014. Structural response of grid-reinforced bituminous pavements. *Materials and structures*, *47*, pp.1391-1408.
10. IRC115 (2014). "Guidelines for Structural Evaluation and Strengthening of Flexible Road Pavements Using Falling Weight Deflectometer (FWD) Technique., Indian Roads Congress, New Delhi, India. "
11. Lytton RL (1989) Use of geotextiles for reinforcement and strain relief in asphalt concrete. Geotext Geomembr 8(3):217–237
12. Nguyen, M.L., Blanc, J., Kerzrého, J.P. and Hornych, P., 2013. Review of glass fibre grid use for pavement reinforcement and APT experiments at IFSTTAR. Road Materials and Pavement Design, 14(sup1), pp.287-308.
13. Nithin, S., Rajagopal, K. and Veeraragavan, A., 2015. State-of-the art summary of geosynthetic interlayer systems for retarding the reflective cracking. Indian geotechnical journal, 45, pp.472-487.
14. Roy, S. and Dixit, M., 2019. Use of glass grid and sami as reinforced interlayer system in runway. In Geotechnics for Transportation Infrastructure: Recent Developments, Upcoming Technologies and New Concepts, Volume 2 (pp. 283-294). Springer Singapore.
15. Safavizadeh, S.A., Wargo, A., Guddati, M. and Kim, Y.R., 2015. Investigating reflective cracking mechanisms in grid-reinforced asphalt specimens: Use of four-point bending notched beam fatigue tests and digital image correlation. Transportation Research Record, 2507(1), pp.29-38.
16. Safavizadeh, S.A., Cho, S.H. and Kim, Y.R., 2022. Interface shear strength and shear fatigue resistance of fibreglass grid-reinforced asphalt concrete test specimens. International Journal of Pavement Engineering, 23(8), pp.2531-2542.