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Research Article

Understanding the pavement project failures in Pakistan: identifying causes and solutions

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Abstract: Pavement deterioration is a major issue in Pakistan's road and highway infrastructure. The current study attempts to clarify the most important factors of road degradation in Pakistan using a questionnaire prepared and distributed to engineers, contractors, architects, surveyors, and project managers involved in road development and upkeep. The study had 147 replies. This data was collected from employees from various road construction sectors in Pakistan. Convenience sampling, a sort of non-probability sampling, is used for data gathering due to time and resource constraints. The data were analysed through SPSS and Microsoft Excel. The responses were gathered using a 10-point Likert scale. The standard (inadequate density in surface or sub-base) has the maximum rank of 9.1, while the lowest factor (use of naturally smooth uncrushed aggregate) is 2.0. Furthermore, the causes of deterioration were reorganised into eight consistent groups of pertinent causes. The first group (effect of traffic load and volume) has a severity level of 6.5, while the last group (effect of bond between layers) ranks 3.22 in group comparison. The study is helpful in identifying the causes of road deterioration in Pakistan and avoiding or mitigating their effects during design, construction, and maintenance through operation.

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1. Introduction

Pavement, the top road layer, is a multi-layered system designed to distribute vehicular loads and withstand traffic and environmental factors (Alaamri *et al.*, 2017). It consists of a subgrade, subbase, and base layer, with the latter typically made of bituminous carpet and macadam (Alaamri *et al.*, 2017). The subgrade, subbase, and pavement base layers are crucial in its performance and longevity. The subgrade provides the foundation for the pavement, while the subbase and base layers help to distribute the load and provide stability. Using stabilised materials in the improper and subbase layers can significantly improve pavement performance (Mohammad & Saadeh, 2008). With proper treatment, locally available soils can also be used in these layers to enhance the pavement's mechanical behaviour. The type and properties of the base and subbase layers, including resilient modulus, material type, and moisture content, are key factors in predicting pavement performance (Su *et al.*, 2017). Based on the types, the pavements are categorised into flexible, rigid, and composite types which are based on load distribution and flexural stiffness. Composite pavements, which consist of a flexible layer over a rigid layer, offer cost-effective and durable alternatives for high-traffic roadways. Semi-flexible composite pavement materials combine the benefits of asphalt concrete and Portland cement concrete, providing better rutting resistance and eliminating the need for joints (Tran *et al.*, 2017).

The choice between flexible and rigid pavements depends on factors such as traffic, climate, foundation, life cost, materials, maintainability, and safety. Road pavement is a crucial component of a nation's infrastructure, supporting economic growth and improving quality of life (Roy, 2021; Lee & Yoo, 2008). It directly impacts ride comfort, vehicle damage, and energy consumption (Lee & Yoo, 2008). Pavement preservation is essential to extend its life and maintain road user expectations (Walker, 2013). Pavement markings are key in communicating information to road users, enhancing safety and efficiency (Carlson *et al.*, 2009). Therefore, road pavement is important because of its contribution to economic development, ride comfort, and safety.

Pavements serve a variety of functions, including providing a smooth and skid-resistant surface, supporting traffic loads, and ensuring durability (Schwartz *et al.*, 2016). Recent advancements have indicated the improvement of smart and multifunctional asphalt combinations, which can promote environmental pollution and contribute to a "Green Recovery" (Segundo *et al.*, 2021). Functional pavement technology has also been applied to create green roads, safe pavements, intelligent roads, and durable roads (Zheng *et al.*, 2020). Additionally, eco-friendly functional road materials, such as permeable asphalt concrete and noise-reducing pavement materials, have been developed to address environmental concerns (Jian *et al.*, 2018). These advancements highlight the diverse and evolving functions of pavements in modern infrastructure.

Pavement deterioration, defined as a decrease in serviceability due to the development of cracks and ruts, is influenced by a range of factors. Gupta *et al.* (2011) developed models to predict the deterioration of the Pavement Condition Index (PCI), with sides focusing on structural and environmental conditions and Gupta incorporating intrinsic and extrinsic factors. Panchmatia *et al.* (2014) highlighted the role of poor drainage and specific concrete properties in the premature joint deterioration of concrete pavements in cold climates. These studies collectively underscore the multifaceted nature of pavement deterioration and the need for comprehensive maintenance and preservation strategies.

Pavement deterioration is a complex issue influenced by a range of factors. Adlinge and Gupta (2013) and Khan and Khan (2020) both emphasise the importance of considering a variety of distresses and causes, including unevenness, cracking, and rutting. Ikechukwu and Hassan (2021) highlight the role of subgrade swelling due to moisture infiltration, particularly in regions with seasonal moisture variations. These studies collectively underscore the need for a comprehensive approach to understanding and addressing pavement deterioration. Pavement deterioration can be caused by a variety of factors, including environmental effects, poor drainage, and material-related distress (Panchmatia *et al.*, 2014; Ramirez *et al.*, 2011). For instance, concrete pavements can experience auto-destructive deterioration due to expansion reactions, which can be mitigated through secondary protection products (Grošek *et al.*, 2021). In cold climates, the entrapment of moisture in joints can lead to freeze-thaw damage, and poor drainage can exacerbate this issue (Panchmatia *et al.*, 2014). Material-linked distress, fatigue, and construction deficiencies can also contribute to premature deterioration in jointed plain concrete pavements (Ramirez *et al.*, 2011). Additionally, pavement texture can deteriorate over time, and models have been developed to predict this deterioration and enhance roadway safety (Riemer & Pittenger, 2012).

Pavement maintenance is a critical aspect of infrastructure management, with various strategies and technologies being employed to extend the maintenance life of pavements. Sarsam (2019) emphasises the role of the Pavement Conservation Management System (PMMS) in this process, which involves inspection, cost analysis, and the prioritisation of maintenance activities. Li *et al.* (2020) introduces the concept of preventive maintenance, which involves early intervention to prevent pavement deterioration. These studies collectively underscore the importance of proactive and systematic maintenance in preserving the integrity and functionality of pavements.

The existing literature on pavement project failure and maintenance techniques reveals several key gaps. Firstly, there is a need for a comprehensive approach that considers both field conditions and maintenance data in fatigue life prediction models (Luo *et al.*, 2023). Secondly, the impact of factors such as utility cuts, maintenance culture, and workmanship on pavement failures in specific regions like Trinidad and Tobago needs further exploration (Leon *et al.*, 2023). Thirdly, the causes of flexible pavement failures, including improper bituminous mixes and heavy traffic loads, require more in-depth analysis (Moghe *et al.*, 2023). Lastly, the relationship between urban drainage challenges and pavement failures, particularly in the context of design and construction defects, needs to be further investigated (Jemberie *et al.*, 2023). These gaps highlight the need for a more holistic understanding of the effects of pavement project failure and the development of effective maintenance techniques.

The research delves into the root causes of pavement deterioration in Pakistan, offering invaluable insights for engineers and contractors to make informed decisions. It enriches maintenance practices and refines design methodologies, striving to prolong the service life of pavements and fortify infrastructure sustainability. The study facilitates targeted interventions and resource allocation by identifying key factors influencing pavement performance. This comprehensive analysis serves as a cornerstone for improving the resilience and longevity of road networks, ultimately contributing to the enhanced transportation efficiency and safety across Pakistan.

2. Literature review

2.1. Pavement

Road pavement reveals a growing focus on sustainability and environmental impact. Xiao *et al.* (2021) and Chhabra and Marik (2014) highlight using recycled construction materials, such as rubber-modified asphalt and waste plastics, in pavement engineering. Lendra *et al.* (2020) emphasises the need for energy-efficient road construction, suggesting the development of energy optimisation models. Jian *et al.* (2018) further explore the concept of eco-friendly functional road materials, including permeable asphalt concrete and noise-reducing pavement materials. These studies collectively underscore the importance of sustainable and environmentally friendly practices in road pavement construction.

2.2. Pavement failure

A range of factors contribute to road pavement deterioration, including poor drainage, traffic overloading, expansive subgrade soils, and the use of low-quality materials (Zumrawi, 2015). Faults caused in construction due to weak construction quality are particularly significant (Tarawneh & Sarireh, 2013). Specific issues, such as compromised air void systems and in-filling of marginal air voids, can also lead to premature deterioration (Rangaraju, 2002). The dynamic nature of road pavements further complicates the maintenance of pavements in good condition. These findings underscore the need for improved construction practices, materials, and maintenance techniques to mitigate road pavement deterioration. A range of factors contribute to common road faults, including traffic overloading, pavement age, road geometry, weather, drainage, construction quality, and materials (Gurule *et al.*, 2022; Zumrawi, 2015; Singh & Sahoo, 2021).

These issues can lead to pavement distress, such as cracks, potholes, and rutting, which can be exacerbated by poor drainage, expansive subgrade soils, and using low-quality materials in construction (Gurule *et al.*, 2022). To address these problems, a comprehensive understanding of pavement, pavement failure, and pavement failure root causes is necessary (Gurule *et al.*, 2022). Various pavement preservation techniques and measures have been recommended to enhance the life of the pavement and delay its failure (Gurule *et al.*, 2022)

2.3. Causes of pavement failure

Specific to concrete pavements, calcium oxychloride formation due to chemical interactions with certain deicing salts can lead to severe damage, with mitigation techniques including reducing cement content and using concrete sealants (Jones *et al.*, 2020). In rigid pavements, the unevenness index, pavement cracking, and rutting are key parameters to consider in maintenance operations, with various preservation techniques available to enhance pavement life (Jichkar, 2021). Lastly, the evaluation of pavement drainage systems is crucial, as the excessive moisture leads to structural distress and reduced load transfer mechanisms (Ghasia *et al.*, 2019).

2.3.1. Influence of cracks and structural degradation

The validity of fractures and structural failure on pavement decline is a complex issue with various contributing factors. Mugume and Kakoto (2020) highlight the role of inappropriate binder grade selection in asphalt pavement cracking, while Elseifi *et al.* (2018) discuss using the finite element method to model crack initiation and propagation in flexible pavements. Sultana *et al.* (2018) examines the impact of flooding on pavement deterioration, finding that while initial structural strength is reduced, it can be regained through post-flooding rehabilitation. Deme (2020) reviews the effect of pavement surface failure on road traffic accidents, emphasising the need for proper maintenance and management. These studies highlight the important role of material selection, modelling approaches, and maintenance in reducing the impact of fissures and structural failures on pavement degradation.

2.3.2. Effect of standards/specifications and policy

The deterioration of pavement is affected by a range of factors, including climate change, environmental effects, and material traits (Mills *et al.*, 2007). Grosek *et al.* (2021) highlight the impact of environmental effects and the behaviour of cement binders, while Mills *et al.* (2007) emphasize the role of climate change in pavement deterioration. Ramirez *et al.* (2011) identify material-related distress, fatigue, and construction deficiencies as causes of premature deterioration in jointed plain concrete pavements. These research studies collectively underscore the complex interplay of standards, specifications, and guidelines in the deterioration of pavement.

2.3.3. Effect of traffic load and volume

Traffic load and volume substantially influence pavement degradation, with overweight loads causing visible damage such as transverse cracking and reduced effective thickness. However, the extreme climatic conditions, particularly the moisture and temperature variations, can also lead to the sudden pavement failure (Kodippily *et al.*, 2012). The pavement surface deformations, which are often exacerbated by heavy traffic, can further reduce the road service capability and the traffic flow. The source of traffic data can also affect the predicted progression rates of pavement deterioration, with actual data leading to higher rates and earlier intervention timing.

2.3.4. Compaction and construction

Compaction and construction, key causes of pavement deterioration, have been extensively studied in recent literature. Jones *et al.* (2020) highlight the role of calcium oxychloride, a byproduct of chemical interactions among cementitious paste and chloride-based deicing salts, in pavement deterioration. Kodikara *et al.* (2018) emphasise intelligent compaction's importance in achieving uniformity and preventing premature pavement failure. Salehi *et al.* (2021) discuss the potential of recycled materials in sustainable pavement construction, while Moriyoshi *et al.* (2021) identify evidence of quantities of organic substances as a significant factor in the deterioration of modern concrete structures and asphalt pavements. These studies collectively underscore the need for further research and advancements in the field of compaction and construction to mitigate pavement deterioration.

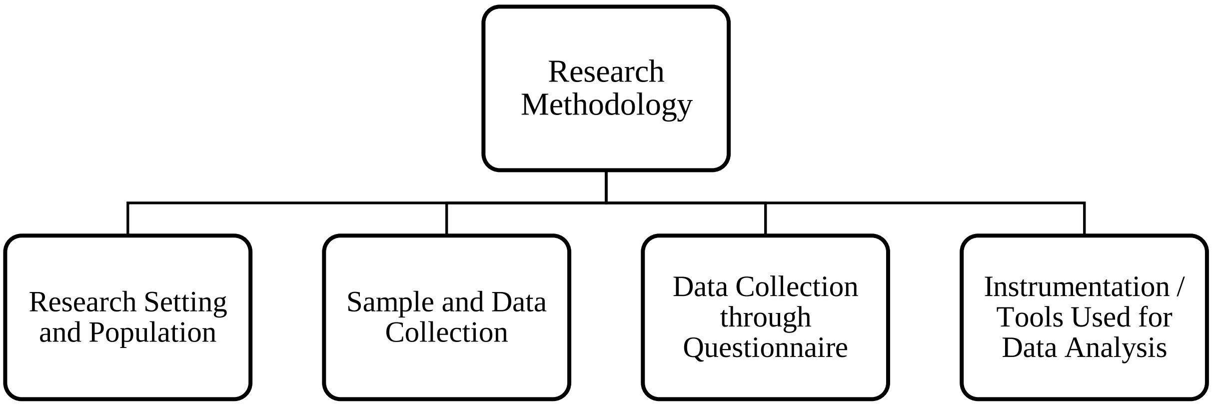
2.3.5. Effect of bond between layers

The attachment among pavement layers is a critical factor in pavement performance, with insufficient adhesion leading to increased stresses and strains (Wang *et al.*, 2017). Moisture damage, which reduces the bond between bitumen and aggregate, is a major cause of pavement deterioration (Omar *et al.*, 2020). Construction practices, such as milling and curing time, can also impact bond strength (Kulkarni, 2018). It is important to characterise and evaluate the bonding property to address these issues, considering factors such as tack coat type, application rate, and surface condition (Yang & Li, 2021).

3. Research methodology

The main objective of the current study is on the variables affecting the performance of highway pavements. Based on previous research and in-person interviews with Pakistani companies, Project managers, and the construction departments involved in road building and upkeep, a group of 41 factors were identified by several researchers, Site engineers, and contractors as likely culprits for pavement deterioration and cracks. These reasons for road deterioration were included in the questionnaire that was created. A panel of experts in questionnaire design were shown the draft design questionnaire. Simultaneously, 25 experts evaluated the 41 recommendations that were thought to cause pavement deterioration. A final reproduction of the survey was distributed to 250 defendants who were chosen from a pre-made list of seasoned engineers working for the major contractor's company.

Figure 1: Research methodology conceptual framework



3.1. Research setting and population

The construction industry, which is constantly involved in development and construction projects, was chosen as the research area for this study. The research's target population is team members who work in construction firms listed in the Pakistan Engineering Council (PEC) directory. PEC is a "statutory body constituted by the government of Pakistan under the PEC Act 1976 (V of 1976), as amended up to December 1, 2016." The Pakistani Engineering Council in Pakistan (2016) provides a comprehensive list of Pakistani construction firms, including engineers, contractors, surveyors, architects, and project managers. The goal was to compile a list of 250 responders who were actively involved in the road construction and maintenance projects. Further, it explores the impact of busyness on survey participation, finding that subjective feelings of busyness can significantly affect participation. These studies collectively emphasise the need for strategies to mitigate the impact of respondent turnover and busyness on survey participation and data quality. For a variety of reasons, however, a senior respondent strategy was chosen for data collection. First, great attention was paid to ensure the plaintiff was qualified to work in the study, had senior occupation and knowledge, and was eager to participate. The majority of the respondents work in the senior management roles in their companies.

3.2. Sample and data collection

The sampling technique is a convenient sampling method because it is better suited to the research design of this inquiry and ensures that respondents participate actively. To increase response rates, respondents were approached via email to complete online Google survey systems or through personal visits to companies. A total of 250 questionnaires were distributed, and 160 people completed and returned their responses. After removing responses with significant missing records, we examined 147 finalised responses, yielding a usable response percentage of 58.8. Table-1 shows the frequencies of responses and ratios seeing the position wise and experience of the construction team.

Table-1: Demographics profiling of respondents

Demographic Variable	Type	Frequency	Percentage
Position	Engineer	53	0.38
	Contractor	35	0.76
	Surveyor	26	60.84
	Architecture	19	25.47
	Project Manager	14	12.55
	Total	147	100.0
Experience	5 and less	71	65.02
	6-13	32	16.35
	14-21	21	10.26
	21-29	18	6.46
	30 and above	5	1.90
	Total	147	100.0

3.3. Design of the questionnaire

The researchers have used the same approach as was adopted by Lamb and Baker (1993) and therefore, the respondents were asked to provide background information. Additionally, they requested that you rate each of the 41 items on a Ten-point Likert scale that could contribute to road deterioration.

3.4. Instrumentation/tools used for data collection and analysis

Data collection was done by questionnaires. The questionnaires were distributed to respondents working in construction organizations. The responses were collected using a 10-point Likert scale, with 0-3 representing low severity, 3-6 representing medium severity, and 6-10 representing high severity." The questionnaire also asks for demographic information. The proposed study would rely on primary data obtained through questionnaires. However, secondary data were gathered by reading relevant literature to complete the study. The responses were gathered using a Google form (online) as well as personal visits where appropriate. The data were analysed through SPSS and Microsoft Excel.

4. Result and discussion

4.1. Causes of pavement project failure

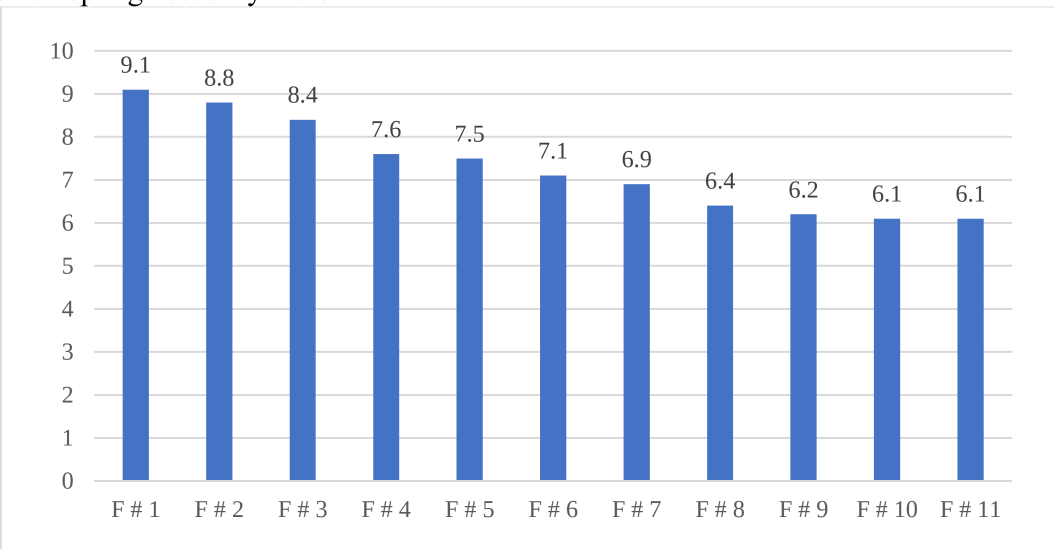
Road weakening individual factor ranking. The questionnaire includes 41 groups linked to road deterioration and is arranged randomly. The construction crew responded with a rating of 1 to 3 (low severity), 3 to 6 (medium severity), and 6 to 10 (high severity). Table-2 shows the individual ranking for the appropriate criteria, ranked from most significant to least important, as received by respondents. The parameter (Insufficient compaction in revealing or sub/base) appears to have the highest rank of 9.1, followed by the factor (Poor the environment condition) at 8.08 and the factor (Construction joint or shrinkage crack (due to low temperature or asphalt hardening) in bitumen surfacing at 8.4 as the maximum 11 factors that led to a severe factor for road deterioration. The lowest contractor level is 2.73 (inadequate resistance to come out of aggregate polishing). The Annexure-I highlights the extra findings.

4.2. Graphical representation of the analysed data

4.2.1. Top 11 high severity factor

From the research study, we found 11 factors whose severity levels are high. The factor with the maximum severity is inadequate compaction in surfacing or sub/base, whose severity level is 9.1, which is a very high level that should be taken seriously in road buildings.

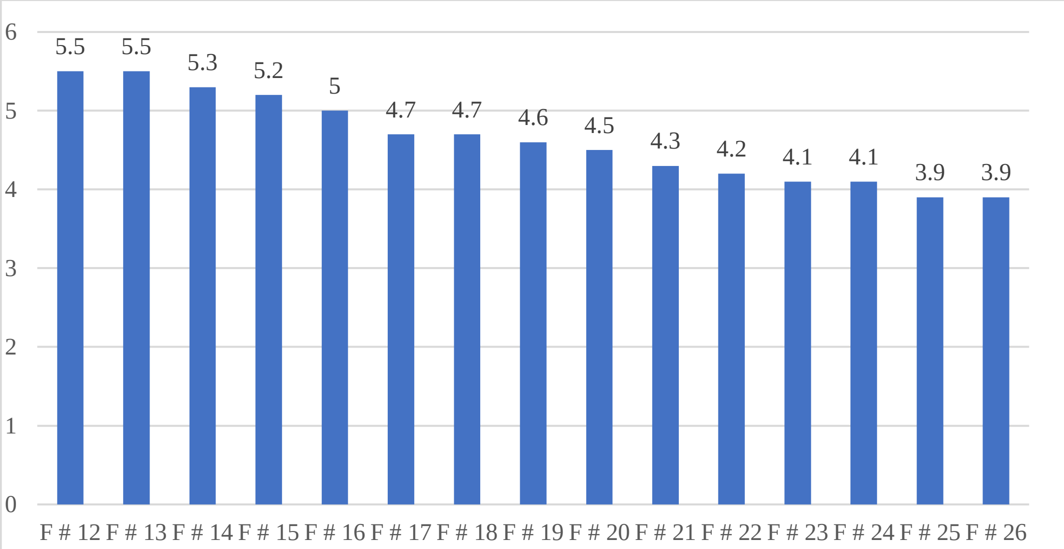
Figure 2: Top high severity factor



4.2.2. Medium severity factor

The figure 3 presents a list of factors contributing to the maintenance, construction, and quality of roads or highways, along with their respective severity ratings. These factors have been categorised based on their impact, with those marked as "Medium severity" denoting issues that pose a significant concern but may not be as critical as higher severity factors. Understanding and addressing these factors are essential for maintaining and improving the condition and performance of road infrastructure.

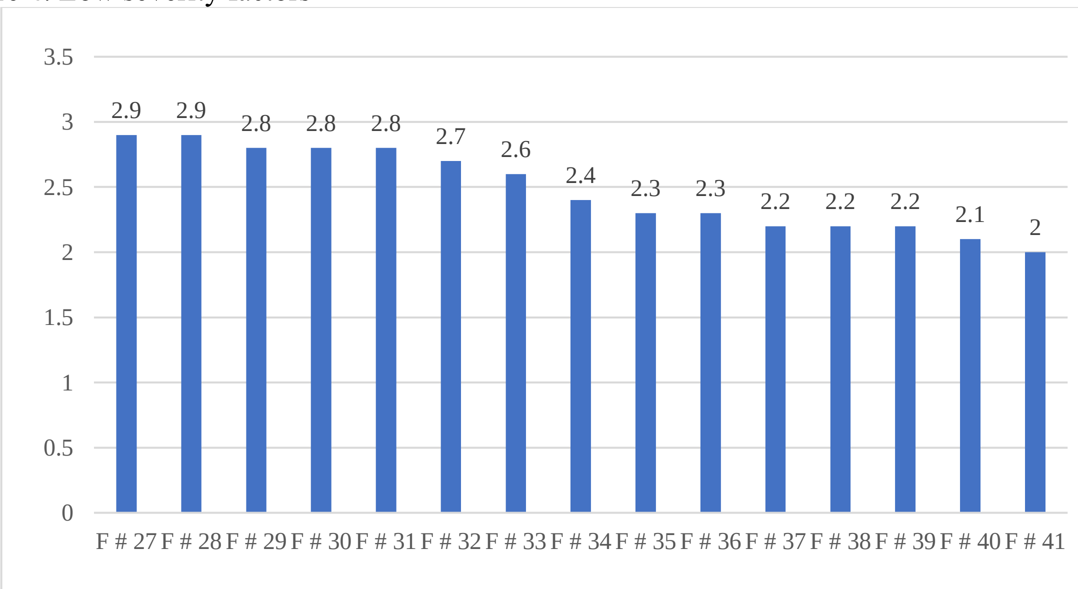
Figure 3: Medium severity factor



4.2.3. Low severity factors

Low severity factors encompass a range of issues that, while not immediately threatening the structural stability of the pavement, can gradually degrade its performance over time if left unaddressed. These factors typically manifest as surface distresses or minor structural deficiencies that do not compromise the overall functionality of the pavement network. Despite their relatively benign nature, low-severity factors merit attention due to their cumulative effect on pavement conditions and the potential for exacerbation if ignored.

Figure 4: Low severity factors



4.3. Road deterioration grouped factor

The factors related to road deterioration essentially are parts of partial groups (relevant factors gathered in one group). These categories are: (1) Effect of cracks and structural failure, (2) Effect of standards/specifications and policy, (3) Effect of traffic load and volume, (4) layer compaction during construction, (5) Effect of bond between layers, (6) AC properties and effect of construction conditions, (7) Effect of the drainage system and groundwater, and (8) Aggregate properties.

4.3.1. Traffic load and volume on road deterioration

Table-2 presents the impact of traffic load and volume on road deterioration, with causes of road cracks and deterioration categorised into individual and grouped factors. The group severity level is 6.5, which includes the effects of traffic load and volume on road deterioration. Specific causes are assigned numerical identifiers (F-10, F-7) and associated scores for both individual and grouped factors.

Table-2: Effect of traffic load and volume group on road deterioration

Effect of Traffic Load and Volume	Individual	Group
F -10	6.1	6.5
F -7	6.9	

4.3.2. Effect of cracks and structural failure on road deterioration

Table-3 outlines the effect of cracks and structural failure on road deterioration. The severity level of this group is 6.45. The grouped factors include the effect of cracks and structural failure, with specific causes denoted by numerical identifiers (F-14, F-3, F-6, F-16) and corresponding scores for both individual and grouped factors.

Table-3: Effect of cracks and structural failure on road deterioration

Effect of cracks and structural failure group	Individual	Group
F-14	5.3	6.45
F-3	8.4	
F-6	7.1	
F-16	5.0	

4.3.3. Compaction and construction

Table-4 examines the influence of compaction and construction on road deterioration. The severity level of this group is 5.62. The grouped factors encompass compaction and construction, with designated causes labelled by numerical identifiers (F-1, F-20, F-21, F-19) and respective scores for both individual and grouped factors.

Table-4: Compaction and construction group

Compaction and Construction	Individual	Group
F-1	9.1	5.62
F-20	4.5	
F-21	4.3	
F-19	4.6	

4.3.4. Effect of standards/specifications and policy

Table-5 elucidates the impact of standards/specifications and policy on road deterioration. The severity level of this group is 5.58. The grouped factors encapsulate the effect of standards/specifications and policy, with specific causes indicated by numerical identifiers (F-36, F-15, F-31, F-18, F-5, F-23, F-12) and corresponding scores for both individual and grouped factors.

Table-5: Effect of standards/specifications and policy

Effect of Standards/Specifications and Policy	Individual	Group
F-36	2.3	
F-15	5.2	
F-31	2.8	
F-18	4.7	5.58
F-5	7.5	
F-23	4.1	
F-12	5.5	

4.3.5. Effect of drainage system and groundwater

Table-6 investigates the influence of the drainage system and groundwater on road deterioration. The severity level of this group is 5.3. The grouped factors encompass the effect of the drainage system and groundwater, with designated causes denoted by numerical identifiers (F-10, F-4, F-38) and respective scores for both individual and grouped factors.

Table-6: Effect of drainage system and groundwater

Effect of Drainage System and Groundwater	Individual	Group
F-10	6.1	
F-4	7.6	5.3
F-38	2.2	

4.3.6. Asphalt Concrete (AC) properties and effect of construction conditions

Table-7 explores the impact of AC properties and construction conditions on road deterioration, the severity level of this group is 4.64. The grouped factors comprise AC properties and the effect of construction conditions, with specific causes labelled by numerical identifiers (F-8, F-27, F-35, F-2, F-30) and corresponding scores for both individual and grouped factors.

Table-7: AC properties and effect of construction conditions

AC Properties and Effect of Construction Conditions	Individual	Group
F-8	6.4	
F-27	2.9	
F-35	2.3	4.64
F-2	8.8	
F-30	2.8	

4.3.7. Aggregate properties group

Table-8 examines the influence of aggregate properties on road deterioration. The severity level of this group is 3.57. The grouped factors encompass aggregate properties, with designated causes indicated by numerical identifiers (F-30, F-9, F-17, F-24, F-33, F-39, F-41, F-26) and respective scores for both individual and grouped factors.

Table-8: Aggregate properties

Aggregate Properties	Individual	Group
F-30	2.9	3.57
F-9	6.2	
F-17	4.7	
F-24	4.1	
F-33	2.6	
F-39	2.2	
F-41	2.0	
F-26	3.9	

4.3.8. Effect of bond between layers

Table-9 outlines the impact of the bond between layers on road deterioration. The severity level of this group is 3.22. The grouped factors include the effect of the bond between layers, with specific causes denoted by numerical identifiers (F-32, F-34, F-37, F-40, F-29, F-25, F-13, F-22) and corresponding scores for both individual and grouped factors.

Table-9: Effect of bond between layers

Effect of Bond Between Layers	Individual	Group
F-32	2.7	3.22
F-34	2.4	
F-37	2.2	
F-40	2.1	
F-29	2.8	
F-25	3.9	
F-13	5.5	
F-22	4.2	

5. Conclusion and recommendation

The pavement failure, characterised by the development of cracks and ruts leading to decreased serviceability, represents a significant challenge in Pakistan's road and highway infrastructure. This study aimed to elucidate the primary factors contributing to the road degradation in Pakistan through a comprehensive analysis of responses from professionals in the construction industry. By utilising a questionnaire distributed to engineers, contractors, architects, surveyors, and project managers involved in the road development and upkeep, coupled with inputs from industry experts, a thorough understanding of the causes of pavement deterioration was achieved.

The study received 147 responses from employees across various construction businesses in Pakistan, enabling a robust analysis of the factors influencing pavement degradation. Despite limitations associated with convenience sampling, the use of a 10-point Likert scale provided valuable insights into the severity of each identified cause, ranging from low to severe. Notably, inadequate density in surface or sub-base emerged as the most significant factor, with a maximum severity rank of 9.1, underscoring the critical importance of proper construction practices in pavement longevity.

Furthermore, categorising causes into eight consistent groups facilitated a structured approach to understanding the multifaceted nature of pavement deterioration. From the effect of traffic load and volume to the impact of bond between layers, each group represents a distinct aspect of road degradation that warrants attention during pavement projects' design, construction, and maintenance phases.

Based on the severity rankings provided for the factors contributing to the pavement failure in Pakistan, the following findings-based recommendations can be proposed to address these issues effectively:

- Enhance compaction practices: Implement rigorous quality control measures to ensure adequate compaction in both surfacing and sub/base layers during pavement construction. This may include employing advanced compaction techniques, such as vibratory rollers, and conducting regular density testing to achieve optimal pavement density and strength.
- Adaptation to climate conditions: Develop resilient pavement designs capable of withstanding the impact of varying climate conditions. This involves selecting appropriate materials and construction techniques that can accommodate temperature fluctuations, freeze-thaw cycles, and other environmental factors to minimise the risk of pavement distress and degradation.
- Preventive maintenance for cracks: Implement proactive measures to prevent and repair construction joints or shrinkage cracks in asphalt surfacing. This may include utilising crack sealing and filling techniques using appropriate materials to prevent water infiltration and preserve the integrity of the pavement layers.
- Improve drainage systems: Enhance drainage design systems to effectively manage surface water runoff and prevent seepage of water through asphalt layers. Proper drainage infrastructure, including ditches, culverts, and drainage pipes, should be installed to redirect water away from the pavement structure and minimise the risk of moisture-induced damage.
- Enhance supervision and quality assurance: Strengthen supervision and quality assurance practices during pavement construction to ensure compliance with design specifications and construction standards. This involves providing adequate training and resources to project supervisors and inspectors to identify and rectify potential issues during construction.
- Address structural deficiencies: Address the structural failures of the pavement base by conducting thorough investigations and implementing the appropriate remedial measures. This method may include reinforcing the base layer, repairing substandard materials, or redesigning the pavement structure to improve load-bearing capacity and durability.
- Manage traffic volume and loading: Develop traffic management strategies to mitigate the impact of large traffic volumes and axial loading on pavement performance. This may involve implementing weight restrictions, optimising traffic flow patterns, and prioritising maintenance activities on heavily trafficked roads to minimise wear and tear on the pavement surface.

A few study limitations are discussed below, which can be addressed in future research. First, the data was gathered from employees working in Pakistan's road construction sector; thus, this framework should be applied in a variety of study settings. Second, a cross-sectional data-gathering approach was used, but longitudinal data-gathering techniques may be useful in future research. Third, due to limited resources, this study only included a small number of respondents. In the future, the number of participants should increase. Finally, this study focused on the causes of pavement project failure; the future research should focus on other types of construction failures, such as building construction project failure and bridge construction failure.

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References

Alaamri, R. S. N., Kattiparuthi, R. A., & Koya, A. M. (2017). Evaluation of flexible pavement failures-a case study on IZKi Road. *International Journal of Advanced Engineering, Management and Science, 3*(7), 741–749. https://doi.org/10.24001/ijaems.3.7.6

Bhargava, N., Siddagangaiah, A. K., & Ryntathiang, T. L. (2019). State of the art review on design and performance of microsurfacing. *Road Materials and Pavement Design, 21*(8), 2091–2125. https://doi.org/10.1080/14680629.2019.1607771

Carlson, P. J., Park, E. S., & Andersen, C. (2009). Benefits of pavement markings. *Transportation Research Record, 2107*(1), 59–68. https://doi.org/10.3141/2107-06

Chhabra, R. S., & Marik, S. (2014). A review literature on the use of waste plastics and waste rubber tyres in pavement. *International Journal of Core Engineering & Management (IJCEM), 1*(1), 1-5. http://www.hindex.org/2014/p442.pdf

Deme, D. (2020). A review on effect of pavement surface failure on road traffic accident. *Journal of Advancement in Engineering and Technology, 7*(3), 1-4. https://doi.org/10.5281/zenodo.3754298

Elseifi, M. A., Baek, J., & Dhakal, N. (2018). Review of modelling crack initiation and propagation in flexible pavements using the finite element method. *International Journal of Pavement Engineering, 19*(3), 251–263. https://doi.org/10.1080/10298436.2017.1345555

Ghasia, M. A., Shah, Y. U., & Rotte, V. M. (2019). A critical review on evaluation of pavement drainage systems. In *Lecture Notes in Civil Engineering* (pp. 93–101). https://doi.org/10.1007/978-981-13-6701-4_5

Grošek, J., Zavřel, T., & Stryk, J. (2021). Mitigation possibilities of concrete pavement degradation. *IOP Conference Series: Materials Science and Engineering, 1039*(1), 012018. https://doi.org/10.1088/1757-899x/1039/1/012018

Gupta, A., Kumar, P., & Rastogi, R. G. (2011). Pavement deterioration and maintenance model for low volume roads. *International Journal of Pavement Research and Technology, 4*(4), 195–202. https://doi.org/10.6135/ijprt.org.tw/2011.4(4).195

Gurule, A., Ahire, T., Ghodke, A., Mujumdar, N. P., & Ahire, G. D. (2022). Investigation on causes of pavement failure and its remedial measures. *International Journal for Research in Applied Science and Engineering Technology, 10*(5), 2786–2788. https://doi.org/10.22214/ijraset.2022.42934

Ikechukwu, A. F., & Hassan, M. M. (2021). Assessing the extent of pavement deterioration caused by subgrade volumetric movement through moisture infiltration. *International Journal of Pavement Research and Technology, 15*(3), 676–692. https://doi.org/10.1007/s42947-021-00044-y

Jemberie, M. A., Melesse, A. M., & Abate, B. (2023). Urban Drainage: The Challenges and Failure Assessment using AHP, Addis Ababa, Ethiopia. *Water, 15*(5), 957. https://doi.org/10.3390/w15050957

Jian, W., Huang, Y., & Sha, A. (2018). A review of eco-friendly functional road materials. *Construction and Building Materials, 191*, 1082–1092. https://doi.org/10.1016/j.conbuildmat.2018.10.082

Jichkar, R. (2021). Review Paper on Defects in rigid pavement. *International Journal for Research in Applied Science and Engineering Technology, 9*(VI), 1288–1290. https://doi.org/10.22214/ijraset.2021.35206

Jones, C., Ramanathan, S., Suraneni, P., & Hale, W. (2020). Calcium oxychloride: A critical review of the literature surrounding the formation, deterioration, testing procedures, and recommended mitigation techniques. *Cement and Concrete Composites, 113*, 103663. https://doi.org/10.1016/j.cemconcomp.2020.103663

Khan, S. S., & Khan, F. (2020). Flexible pavements deterioration and solutions. *International Journal of Advance Research, Ideas and Innovations in Technology, 6*(3), 468–470. https://www.ijariit.com/manuscript/flexible-pavements-deterioration-and-solutions/

Kodikara, J., Islam, T., & Sounthararajah, A. (2018). Review of soil compaction: History and recent developments. *Transportation Geotechnics, 17*, 24–34. https://doi.org/10.1016/j.trgeo.2018.09.006

Kodippily, S., Henning, T. F. P., & Ingham, J. (2012). Detecting flushing of thin-sprayed seal pavements using pavement management data. *Journal of Transportation Engineering, 138*(5), 665–673. https://doi.org/10.1061/(asce)te.1943-5436.0000354

Kulkarni, A. A. (2018). Construction practices and its effect on bond strength of pavements. *Journal of Today's Ideas Tomorrow's Technologies, 6*(2), 77–82. https://doi.org/10.15415/jotitt.2018.62006

Lamb, C. W., & Baker, J. (1993). The case method of instruction: Student-Led presentations and videotaping. *Marketing Education Review, 3*(1), 44–50. https://doi.org/10.1080/10528008.1993.11488397

Lee, S. H., & Yoo, I. K. (2008). Overview of Pavement Management System in Korea and Its Operation Results. In *25th International Symposium on Automation and Robotics in Construction. Vilnius Gediminas Technical University Publishing House "Technika," Vilnius, Lithuania* (pp. 355-364).

Leon, L. P., Ellis, L. A., Martin, H. H., & Fermin, B. (2023). Dominating factors of road failures: perceptions of key stakeholders in the small island developing state of Trinidad and Tobago. *West Indian Journal of Engineering, 45*(2), 68–76. https://doi.org/10.47412/mgbb4897

Lendra, L., Wibowo, M. A., & Hatmoko, J. U. D. (2020). Literature review on energy consumption in road construction projects. *Journal of Physics: Conference Series, 1625*(1), 012034. https://doi.org/10.1088/1742-6596/1625/1/012034

Luo, X., Wang, H. B., Cao, S., Jian, L., Yang, S., & Zhang, Y. (2023). A hybrid approach for fatigue life prediction of in-service asphalt pavement. *Philosophical Transactions of the Royal Society, 381*(2254). https://doi.org/10.1098/rsta.2022.0174

Mills, B., Tighe, S., Andrey, J., Smith, J., Parm, S., & Huen, K. (2007). *Road well-travelled: implications of climate change for pavement infrastructure in Southern Canada.* Transportation Association of Canada. https://trid.trb.org/view/859037

Moghe, A. B., Chavhan, J. R., Rathod, B. M., Gedam, D. S., Pawar, A. V., Ade, P. D., & Rathod, V. (2023). Study and analysis of highway failure and their maintenance. *International Journal for Research in Applied Science and Engineering Technology, 11*(10), 1370–1376. https://doi.org/10.22214/ijraset.2023.56151

Mohammad, L. N., & Saadeh, S. (2008). Performance evaluation of stabilized base and subbase material. *Geo Congress*. https://doi.org/10.1061/40971(310)134

Moriyoshi, A., Shibata, E., Natsuhara, M., Saito, K., Kondo, T., & Kasahara, A. (2021). Deterioration of modern concrete structures and asphalt pavements by respiratory action and trace quantities of organic matter. *PLOS ONE, 16*(5), e0249761. https://doi.org/10.1371/journal.pone.0249761

Mugume, M. R., & Kakoto, D. (2020). Effect of inappropriate binder grade selection on initiation of asphalt pavement cracking. *Sustainability, 12*(15), 6099. https://doi.org/10.3390/su12156099

Omar, H. A., Yusoff, N. I. M., Mubaraki, M., & Ceylan, H. (2020). Effects of moisture damage on asphalt mixtures. *Journal of Traffic and Transportation Engineering (English Edition), 7*(5), 600–628. https://doi.org/10.1016/j.jtte.2020.07.001

Panchmatia, P., Olek, J., & Whiting, N. (2014). Joint deterioration in concrete pavements. In *4th International Conference on the Durability of Concrete Structures* (pp. 12-21) https://doi.org/10.5703/1288284315377

Ramirez, L., Geary, M., Vandenbossche, J. M., Gatti, K. A., & Mu, F. (2011). Premature Deterioration of Jointed Plain Concrete Pavements. *United States Department of Transportation*. https://rosap.ntl.bts.gov/view/dot/20537

Rangaraju, P. R. (2002). Investigating premature deterioration of a concrete highway. *Transportation Research Record, 1798*(1), 1–7. https://doi.org/10.3141/1798-01

Riemer, C., & Pittenger, D. (2012). Modeling pavement texture deterioration as a Pavement Preservation Management System tool. *Transportation Research Board 91st Annual Meeting Transportation Research Board*. https://trid.trb.org/view/1128974

Roy, P. P. (2021). Study on rigid pavement analysis and design. *International Journal for Research in Applied Science and Engineering Technology, 9*(8), 1842–1850. https://doi.org/10.22214/ijraset.2021.37672

Salehi, S., Arashpour, M., Kodikara, J., & Guppy, R. (2021). Sustainable pavement construction: A systematic literature review of environmental and economic analysis of recycled materials. *Journal of Cleaner Production, 313*, 127936. https://doi.org/10.1016/j.jclepro.2021.127936

Sarsam, S. I. (2016). Pavement maintenance management system: a review. *Trends in Transport Engineering and Applications*, *3*(2), 19-30. https://doi.org/10.3759/ttea.v3i2.2850

Schwartz, C. W., Christopher, B. R., & Tutumluer, E. (2016). Geotechnical aspects of pavements: there's more to roads than asphalt and concrete. *GEOSTRATA Magazine*, 20(3), 44–50. https://doi.org/10.1061/geosek.0000335

Segundo, I. R., Freitas, E. F., Branco, V. T. F. C., Landi, S., Costa, M. F. M., & Carneiro, J. a. O. (2021). Review and analysis of advances in functionalized, smart, and multifunctional asphalt mixtures. *Renewable & Sustainable Energy Reviews, 151*, 111552. https://doi.org/10.1016/j.rser.2021.111552

Shahid, M. A. (2019). Maintenance management of pavements for expressways in Malaysia. *IOP Conference Series: Materials Science and Engineering, 512*, 012043. https://doi.org/10.1088/1757-899x/512/1/012043

Singh, A. K., & Sahoo, J. P. (2021). Rutting prediction models for flexible pavement structures: A review of historical and recent developments. *Journal of Traffic and Transportation Engineering (English Edition), 8*(3), 315–338. https://doi.org/10.1016/j.jtte.2021.04.003

Su, N., Xiao, F., Wang, J., & Amirkhanian, S. (2017). Characterizations of base and subbase layers for mechanistic-empirical pavement design. *Construction and Building Materials, 152*, 731–745. https://doi.org/10.1016/j.conbuildmat.2017.07.060

Sultana, M., Chai, G., Chowdhury, S. H., Martin, T., Anissimov, Y. G., & Rahman, A. (2018). Rutting and roughness of flood-affected pavements: literature review and deterioration models. *Journal of Infrastructure Systems, 24*(2). https://doi.org/10.1061/(asce)is.1943-555x.0000413

Tarawneh, S., & Sarireh, M. (2013). Causes of cracks and deterioration of pavement on highways in Jordan from contractors' perspective. *Civil and Environmental Research, 3*(10), 16–26. https://iiste.org/Journals/index.php/CER/article/view/7718

Tran, T. N., Nguyen, H. N., Nguyen, K. S., & Nguyen, N. (2017). Semi-flexible material: the sustainable alternative for the use of conventional road materials in heavy-duty pavement. In Lecture Notes in Civil Engineering (pp. 552–559). https://doi.org/10.1007/978-981-10-6713-6_54

Walker, D. (2013). The importance of preserving pavements. *Asphalt, 28*(1). https://trid.trb.org/view/1314923

Wang, J., Xiao, F., Chen, Z., Li, X., & Amirkhanian, S. (2017). Application of tack coat in pavement engineering. *Construction and Building Materials, 152*, 856–871. https://doi.org/10.1016/j.conbuildmat.2017.07.056

Xiao, Y., Dong, Q., Chang, X., Cui, P., & Liu, G. (2021). Research hotspots and development trends on recycled construction materials in Pavement Engineering: a bibliometric evaluation. *Materials, 14*(9), 2170. https://doi.org/10.3390/ma14092170

Yang, K., & Li, R. (2021). Characterization of bonding property in asphalt pavement interlayer: a review. *Journal of Traffic and Transportation Engineering (English Edition), 8*(3), 374–387. https://doi.org/10.1016/j.jtte.2020.10.005

Zheng, J., You, Z., & Liu, X. (2020). Achievements and prospects of functional pavement: materials and structures. *Applied Sciences, 10*(21), 7720. https://doi.org/10.3390/app10217720

Zumrawi, M. M. E. (2015). Investigating causes of pavement deterioration in Khartoum State, Sudan. *Journal of Civil and Environmental Engineering, 9*(11), 1458–1463. https://publications.waset.org/10002917/investigating-causes-of-pavement-deterioration-in-khartoum-state-sudan

Annexure-I: Factors in decanting order

S.No.	Causes of Pavement Project Failure	Individual Severity Level
F-1	Inadequate compaction in surfacing or sub/base	9.1
F-2	Poor climate condition	8.8
F-3	Construction joint or shrinkage crack (due to low temperature or bitumen hardening) in asphalt surfacing	8.4
F-4	Seepage of water through asphalt breaks the bond between the surface and lower layers	7.6
F-5	Poor supervision	7.5
F-6	Structural failure of the base	7.1
F-7	Large traffic volume using the road	6.9
F-8	Shrinkage & fatigue of brittle base or wearing course	6.4
F-9	Low stiffness base and poor material	6.2
F-10	Poor drainage design system	6.1
F -11	Large axial traffic loading	6.1
F-12	Poor maintenance policy/culture	5.5
F-13	Weak, loose layer immediately under laying seal	5.5
F-14	Reflection of a shrinkage crack or joint in an underlying base	5.3
F-15	Poor highway facilities	5.2
F-16	Defects caused during construction due to poor construction quality	5.0
F-17	Poor material quality on sub/base layers	4.7
F-18	Poor local standard of practice	4.7
F-19	inadequate rolling before opening to traffic	4.6
F-20	Inadequate strength (stability) in surfacing or base	4.5
F-21	inadequate compaction, construction during wet or cold weather	4.3
F-22	Inadequate cleaning or inadequate tack coat before placement of upper layers	4.2
F-23	Poor laboratory and in situ tests on soil	4.1
F-24	Deterioration of binder and/or stone	4.1
F-25	Weak seal coat, loss of adhesion to base	3.9
F-26	inferior asphalt mix design	3.9
F-27	Fatigue cracking of AC wearing course	2.9
F-28	Stone deterioration	2.9
F-29	Ageing or absorption of blinder	2.8
F-30	Ice and snow	2.8
F-31	Inadequate sanctions for highway failure	2.8
F-32	Poor bond between pavement layers	2.7
F-33	Hydrophilic aggregate	2.6
F-34	Low binder content	2.4
F-35	Shrinkage and binder oxidation in AC or sprayed surfacing due to the effect of age and environment	2.3
F-36	Low knowledge base	2.3
F-37	Poor blinder-to-stone adhesion	2.2
F-38	High ground water level	2.2
F-39	Inadequate resistance to polishing of surface aggregate	2.2
F-40	Incorrect blending of binder	2.1
F-41	Use of naturally smooth uncrushed aggregate	2.0