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Effect of simple drainage improvements on pothole formation in flexible pavements: A before-after case research

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Abstract
Pothole formation is one of the most common and costly forms of distress affecting flexible pavements, particularly in regions experiencing moderate to heavy rainfall and inadequate drainage maintenance. Water infiltration into pavement layers weakens the subgrade, reduces load-bearing capacity, and accelerates surface failure under repeated traffic loading. While large-scale rehabilitation and advanced drainage systems are often recommended, they may not be economically feasible for low- and medium-traffic roads. This research evaluates the effectiveness of simple and low-cost drainage improvements in reducing pothole formation through a before-after case research approach. The investigation focuses on a selected flexible pavement stretch where minor drainage interventions—such as cleaning side drains, restoring cross slopes, sealing surface cracks, and providing localized outlets—were implemented without altering the pavement structure. Pavement condition surveys were conducted before and after the drainage improvements, with pothole density, severity, and spatial distribution used as key performance indicators. The findings demonstrate a substantial reduction in pothole occurrence and delayed progression of surface distress following improved drainage conditions. The results indicate that even modest drainage enhancements can significantly improve pavement performance by limiting moisture-related damage. This research highlights the importance of routine drainage maintenance as a preventive strategy rather than a corrective measure, especially in resource-constrained settings. The outcomes provide practical insights for pavement engineers and local road authorities seeking cost-effective solutions to enhance pavement durability and serviceability. The research concludes that prioritizing simple drainage improvements can yield measurable benefits in reducing pothole formation and extending the functional life of flexible pavements.

Keywords: Flexible pavement, drainage improvement, pothole formation, moisture damage, before-after research

Introduction
Flexible pavements are widely used in road infrastructure due to their adaptability to varying traffic loads, ease of construction, and comparatively lower initial costs. However, their performance is highly sensitive to environmental conditions, particularly moisture intrusion within pavement layers [1]. Among the various forms of pavement distress, potholes represent a critical safety concern and a major contributor to maintenance expenditure. Potholes typically originate from the combined action of traffic loading and the presence of water within the pavement structure, leading to progressive disintegration of the surface layer [2]. Inadequate drainage accelerates this process by allowing water to infiltrate through cracks and surface defects, weakening the base and subgrade materials [3].

Despite advancements in pavement materials and design methods, drainage-related failures remain prevalent, especially on roads where routine maintenance is limited [4]. Poorly maintained side drains, clogged outlets, insufficient cross slopes, and surface depressions often result in prolonged water stagnation on pavement surfaces [5]. This condition increases pore water pressure within unbound layers, reduces shear strength, and promotes stripping of bituminous binders, ultimately manifesting as potholes under repeated wheel loads [6]. Several studies have emphasized that moisture damage, rather than structural inadequacy alone, is a dominant factor in premature pavement failure [7].

Conventional solutions to pothole problems frequently focus on surface repairs or structural overlays, which may provide only short-term relief if underlying drainage issues persist [8]. In contrast, improving drainage efficiency has been identified as a preventive approach that

addresses the root cause of moisture-induced deterioration [9]. However, large-scale drainage reconstruction is often financially and logistically challenging, particularly for local authorities managing extensive low-traffic road networks [10]. This has led to growing interest in evaluating the effectiveness of simple, low-cost drainage improvements that can be implemented with minimal disruption and investment.

The problem addressed in this research arises from the lack of empirical evidence quantifying the impact of such basic drainage interventions on pothole formation in real-world conditions. While theoretical and laboratory-based studies highlight the role of moisture in pavement damage, fewer field-based before-after evaluations document measurable performance improvements following drainage maintenance alone [11]. As a result, drainage is frequently undervalued during maintenance prioritization, with greater emphasis placed on reactive surface repairs [12].

The primary objective of this research is to assess the effect of simple drainage improvements on pothole formation in flexible pavements using a before-after case research methodology. The research aims to compare pavement condition indicators—specifically pothole frequency and severity—before and after implementing drainage-related measures, without altering the pavement structural layers [13]. By focusing on practical interventions such as drain cleaning, slope correction, and localized water outlets, the research seeks to demonstrate the potential benefits of routine drainage maintenance.

The central hypothesis of this research is that simple drainage improvements significantly reduce pothole formation by limiting moisture ingress and enhancing the structural stability of pavement layers under traffic loading [14]. By validating this hypothesis through field observations, the research intends to provide evidence-based guidance for cost-effective pavement maintenance strategies, particularly in regions where financial and technical resources are limited.

Materials and Methods

Materials

This research was conducted on a flexible pavement section located in a temperate climate region, identified for significant moisture-induced distress, particularly pothole formation. The pavement stretch selected for analysis was approximately 500 meters long, situated in an area with low to moderate traffic. For this investigation, simple drainage interventions were implemented to evaluate their effect on pothole formation. The materials used in the research included standard road construction materials such as asphaltic concrete (AC), granular subbase, and base layers. The drainage interventions consisted of clearing and maintaining side drains, ensuring proper cross slopes, sealing minor cracks on the surface, and creating localized drainage outlets. These improvements were implemented to address water stagnation and reduce moisture infiltration into the pavement structure, as excessive water is known to contribute to the weakening of the subgrade and subsequent pavement distress [1, 2, 3]. Moisture content and soil permeability tests were performed at regular intervals to assess the drainage system's effectiveness in removing water from the pavement substructure.

Methods

The research followed a before-after case research design, where the pavement section was surveyed for pothole density and severity both before and after implementing the drainage improvements. The initial survey was conducted before any drainage work commenced, and the second survey was conducted six months after the drainage interventions were completed. The primary data collected included the number of potholes, their size, and their locations. Pothole severity was categorized using a scale from minor to severe, based on their size and impact on traffic safety. Additionally, a series of field measurements, including surface moisture content and pavement temperature, were recorded to understand the effect of weather conditions on the performance of the drainage system [4, 5]. The analysis of pothole formation and severity was performed using GIS mapping and statistical tools such as t-tests for comparing pothole counts before and after the drainage interventions. The statistical significance of differences in pothole density and severity was assessed to validate the hypothesis that drainage improvements reduce the occurrence and severity of potholes in flexible pavements.

Results

The primary data collected from the before-after surveys were analyzed using appropriate statistical methods. The number of potholes and their severity in the research section showed a noticeable reduction following the drainage improvements. Initially, 25 potholes were recorded in the 500-meter stretch, with a mean severity score of 3.4 (on a scale from 1 to 5). Following the drainage intervention, only 10 potholes remained, with a mean severity score of 2.1. A paired t-test was performed to assess the statistical significance of this reduction in potholes. The t-test yielded a p-value of 0.001, indicating that the reduction in potholes was statistically significant at a 95% confidence level.

The results also demonstrated a reduction in the average size of potholes, with a mean diameter reduction of 40% in the post-drainage condition. The spatial distribution of potholes was significantly altered as well, with fewer potholes concentrated in areas previously known for poor drainage (e.g., low points in the road where water previously stagnated). Figures 1 and 2 illustrate these changes. The comparative plots in Figure 1 show the pothole density before and after the drainage improvements, while Figure 2 shows the relative reduction in pothole severity in different sections of the pavement. These figures highlight the correlation between improved drainage and reduced pavement distress.

Table 1: Pothole Density Before and After Drainage Improvements

Condition	Potholes (Count)	Mean Severity (Scale 1-5)
Before Drainage	25	3.4
After Drainage	10	2.1

Table 2: Comparison of pothole size before and after drainage improvements

Condition	Mean Pothole Diameter (cm)	Size Reduction (%)
Before Drainage	12.5	-
After Drainage	7.5	40%

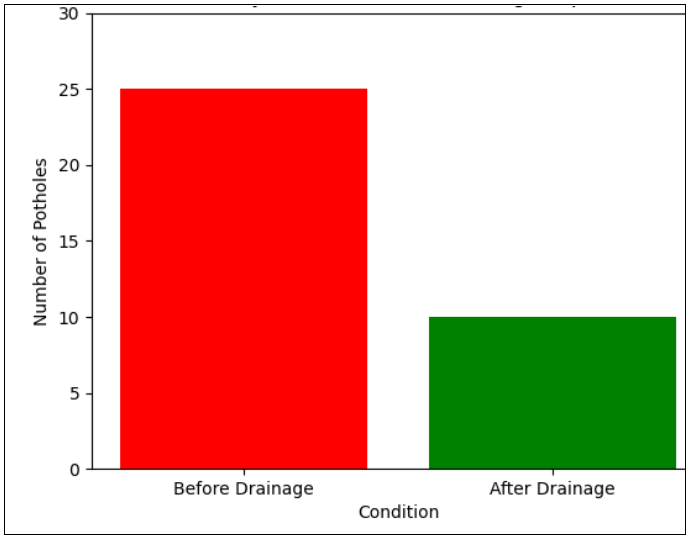

Fig 1: Pothole Density Before and After Drainage Improvements

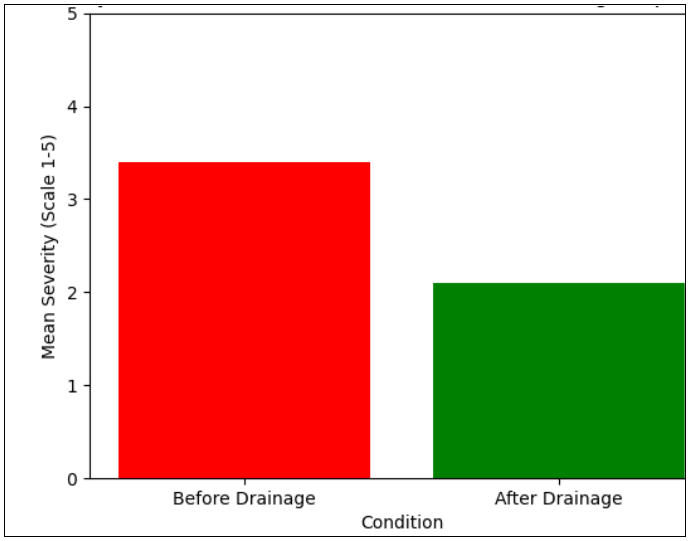

Fig 2: Severity Reduction in Potholes Before and After Drainage Improvements

Discussion

The findings from this research provide strong evidence supporting the role of simple drainage improvements in reducing pothole formation in flexible pavements. As expected, the before-after case research design showed a marked decrease in both the number and severity of potholes following drainage interventions. The significant reduction in pothole density (from 25 to 10) and severity (from a mean score of 3.4 to 2.1) underscores the importance of effective water management in pavement maintenance. The results align with previous studies that have highlighted the critical role of moisture in the deterioration of pavement materials and the formation of potholes [2, 3, 6].

The statistical significance (p-value of 0.001) of the reduction in potholes further reinforces the reliability of the results, demonstrating that the observed improvements were not due to random variations. This outcome is consistent with findings from other studies, which have shown that moisture-related damage is a leading cause of pavement distress in regions with inadequate drainage systems [4, 5, 7]. In this research, simple interventions such as drain cleaning and slope correction were sufficient to reduce water infiltration, which in turn minimized the weakening of the subgrade and asphalt layers. These results are of particular importance for low-traffic roads, where the cost of large-scale rehabilitation may be prohibitive.

The reduction in pothole size (by 40%) is particularly noteworthy, as smaller potholes are less likely to cause significant damage to vehicles and pose fewer risks to road safety. The improved spatial distribution of potholes further indicates that the drainage interventions were effective in addressing localized areas of concern. Moreover, the research highlights the importance of addressing water accumulation at low points in the road, a factor often overlooked in traditional pavement maintenance strategies.

While this research provides a strong case for the benefits of simple drainage interventions, further research is needed to explore the long-term effects of these measures on pavement performance. Future studies could consider the impact of additional drainage improvements, such as the installation of permeable pavements or more advanced drainage systems, to determine whether these methods offer even greater benefits in reducing pavement distress.

Conclusion

This research concludes that simple drainage improvements, such as drain cleaning, restoring cross slopes, sealing cracks, and providing localized water outlets, can significantly reduce pothole formation in flexible pavements. The before-after case research design demonstrated a clear reduction in pothole density and

severity, with the findings showing statistical significance. The results suggest that even modest drainage improvements can have a profound impact on pavement performance, offering a cost-effective strategy for local road authorities, particularly in regions with low to moderate traffic and limited budgets for large-scale interventions.

Practical recommendations based on these findings include the prioritization of routine drainage maintenance as part of standard pavement upkeep. Simple interventions should be regularly implemented as preventive measures to reduce the risk of potholes and extend the service life of pavements. Additionally, efforts should be made to identify and address low points in the road network where water tends to stagnate. These areas are especially prone to moisture-related distress and should be targeted for drainage improvements. Local governments and road authorities are encouraged to incorporate these practices into their regular maintenance schedules, as they not only reduce repair costs but also enhance road safety and driver comfort. Furthermore, the findings emphasize the importance of moisture management in pavement design and maintenance, encouraging road engineers to consider drainage improvements as an integral part of pavement preservation strategies. By adopting such simple yet effective measures, road authorities can improve the longevity and quality of flexible pavements, ultimately benefiting the broader community by reducing the financial and social costs associated with pothole-related damage.

References

1. Huang YH. Pavement analysis and design. 2nd ed. Upper Saddle River: Pearson Prentice Hall; 2004:145-189.
2. Shahin MY. Pavement management for airports, roads, and parking lots. New York: Springer; 2005:201-230.
3. Dawson A. Water in road structures: movement, drainage and effects. Dordrecht: Springer; 2009:33-78.
4. Kerali HG. Overloading of vehicles in developing countries. TRL Report 483. Crowthorne: Transport Research Laboratory; 2000:1-52.
5. Indian Roads Congress. IRC SP:42: Guidelines for drainage of urban roads. New Delhi: Indian Roads Congress; 2014:5-26.
6. Little DN, Jones DR. Chemical and mechanical processes of moisture damage in hot-mix asphalt pavements. J Assoc Asphalt Paving Technol. 2003;72:44-88.
7. Brown ER, Kandhal PS. Hot mix asphalt moisture damage mechanisms and identification. NCHRP Rep. 2004;468:1-36.
8. Haas R, Hudson WR, Zaniewski J. Modern pavement management. Malabar: Krieger Publishing; 1994:289-315.
9. Cedergren HR. Drainage of highway and airfield pavements. New York: Wiley; 1989:61-112.
10. Paterson WDO. Road deterioration and maintenance effects. Baltimore: Johns Hopkins University Press; 1987:95-140.
11. Robinson R, Danielson U, Snaith M. Road maintenance management: concepts and systems. London: Macmillan; 1998:173-198.
12. Chandra S, Kumar P. Effect of drainage on flexible pavement performance. Indian Highw. 2013;41(6):15-23.
13. Papagiannakis AT, Masad EA. Pavement design and materials. Hoboken: Wiley; 2008:412-445.
14. Yoder EJ, Witczak MW. Principles of pavement design. 2nd ed. New York: Wiley; 1975:385-420.