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Social impact of failures in laminated concrete roads on collapsible soils in urban pavements

Impacto social de las fallas en vías de concreto laminado sobre suelos colapsables en pavimentos urbanos

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Abstract
The main objective of this research was to evaluate the social impact generated by failures in roller-compacted concrete pavements on urban roads located on collapsible soils in Huancayo. To this end, sections with visible pavement damage were selected to understand the perceptions of users who regularly travel on these roads. The methodology applied was a descriptive and correlational study. The population consisted of residents who regularly use these roads, and a stratified probability sampling based on vehicular and pedestrian volume was applied. Thus, the sample consisted of 250 people, distributed proportionally according to the traffic intensity on each section. The analysis included descriptive statistics to characterize the sample and the relevant variables, and bivariate correlations were performed using Spearman's Rho. In addition, a structural equation model, developed in SmartPLS, was used to represent the relationships between variables. The results showed that failures in roller-compacted concrete pavements on collapsible soils have a significant social impact on residents traveling on the studied routes in Huancayo, highlighting the importance of considering these effects in urban planning and maintenance.

Keywords: social impact, roller-compacted concrete, collapsible soils.

Resumen
El objetivo principal de esta investigación fue evaluar el impacto social generado por fallas en pavimentos de concreto compactado con rodillo en vías urbanas ubicadas sobre suelos colapsables en Huancayo. Para ello, se seleccionaron tramos con daños visibles en el pavimento, con el fin de comprender la percepción de los usuarios que transitan regularmente por dichas vías. La metodología aplicada correspondió a un estudio descriptivo y correlacional. La población estuvo constituida por ciudadanos habituales de estas vías, y se aplicó un muestreo probabilístico estratificado basado en el volumen vehicular y peatonal. Así, la muestra quedó integrada por 250 personas, distribuidas proporcionalmente según la intensidad de tráfico en cada tramo. El análisis incluyó estadística descriptiva para caracterizar la muestra y las variables relevantes, y se realizaron correlaciones bivariadas mediante Rho de Spearman. Además, se empleó un modelo de ecuaciones estructurales, desarrollado en SmartPLS, para representar las relaciones entre variables. Los resultados mostraron que las fallas en pavimentos de concreto compactado con rodillo sobre suelos colapsables tienen un impacto social significativo en los ciudadanos que circulan por las rutas estudiadas en Huancayo, destacando la importancia de considerar estos efectos en la planificación y mantenimiento urbano.

Palabras clave: impacto social, concreto compactado con rodillo, suelos colapsables.

Introduction
Soil collapse is internationally recognized as one of the main factors affecting the stability of infrastructure, especially rigid pavements and shallow foundations. This phenomenon occurs in unsaturated metastable soils,

which, as their moisture content increases, experience an abrupt loss of internal strength and a significant volumetric reduction. Barden et al. (1973), cited by Opukumo et al. (2022), relate these conditions to parameters such as dry density and void ratio.

In cities like Huancayo, Peru, studying the behavior of collapsible soils in urban areas represents one of the greatest challenges of modern civil engineering, due to the combination of geotechnical and climatic characteristics that generate highly vulnerable scenarios for road infrastructure. Although widely described in the international literature, this phenomenon remains a challenge for local practice, where empirical solutions are often employed that do not guarantee the durability or optimal performance of the works.

It is important to highlight that soil collapse on urban roads goes beyond the structural level and affects the quality of life of those who travel on them. Failures and deformations hamper daily mobility, increase travel times, raise transportation costs, and pose risks to road safety, particularly impacting vulnerable populations who depend on public transportation and stable pedestrian routes. According to a report by the Development Bank of Latin America and the Caribbean (Alcalá et al., 2023), pavement deterioration causes failures in road infrastructure that affect urban mobility.

This phenomenon occurs in metastable sedimentary deposits composed of particles held together by low-strength capillary or cementitious bonds. These soils, although highly resilient in the dry state, lose the forces of attraction between particles when saturated, causing a sudden and significant volumetric reduction. This behavior has been reported in loess soils, unconsolidated alluvial deposits, and volcanic materials in several regions. In Peru, they are common in areas with marked seasonal variations between dry periods and intense rains, such as Huancayo, where humidity cycles favor differential settlements and premature deterioration of urban pavements (López et al., 2022).

Several studies have addressed this issue (Carreira, 2019; Choque & Huachalla, 2022; Saravia, 2018). For example, Choque & Huachalla (2022) revealed the potential for collapse using various criteria and analysis methods for collapsible soils, providing evidence of their hydromechanical behavior and the effects of collapse. They highlight the importance of integrating these parameters into structural design to avoid premature failure and extend pavement life in urban contexts such as Huancayo.

In the region, recent research indicates that the collapse rate under a load of 0.50 kg/cm² ranges between 2.9% and 3.9%, while under a load of 1.00 kg/cm² it varies between 3.5% and 5.2%. Considering that these results indicate collapsible soil conditions, the implementation of soil improvement techniques is recommended (Cañi, 2021). Likewise, Castillo & Reyes (2024) conducted excavations and *in-situ* and laboratory analyses, determining that the predominant soil is silty sand (SM) with good drainage and medium bearing capacity. A water table level of 1.20 meters was recorded, a relevant factor for design and allowable capacity.

Faced with this problem, roller-compacted concrete (RCC) is presented as an efficient alternative for urban pavements, thanks to its strength, durability, and ease of construction. However, its structural performance depends largely on its interaction with the foundation soil. If the base is composed of collapsible materials, the concrete slab may be subjected to additional stresses, accelerating cracking, deformation, and premature failure. Therefore, the optimal design of RCC on urban roads in Huancayo must rigorously incorporate soil-pavement interaction, using advanced geotechnical models that evaluate the effect of collapse on pavement performance throughout its service life.

In addition to its technical advantages, RCC offers economic benefits that favor its viability in urban solutions, allowing construction companies to reduce costs while benefiting road users. Akhnoukh et al. (2025) demonstrated that the use of RCC results in significant material savings, especially on roads with low subgrade strength and high traffic volumes. However, the resulting differential settlements and cracks can affect daily mobility, increase costs, and compromise road safety.

From a geotechnical perspective, collapsible soils are characterized through specific tests, such as the constant-load oedometer with varying humidity, which determines their collapse potential under various conditions. Key parameters such as dry density, porosity index, fines content, and unconfined compressive strength help predict mechanical behavior and susceptibility to collapse. However, the spatial variability of these deposits and the lack of integrated methodologies hinder their application in the design of RCC pavements (Yuan et al., 2021).

Despite progress in understanding soil collapse, there remains a need for methodologies that integrate geotechnical and social aspects related to failure in RCC pavements. This deficiency limits the design of durable and stable pavements, reducing the ability to mitigate negative impacts on mobility, economy, and safety. Furthermore, the significant spatial and temporal variability of collapsible soils in Huancayo makes it difficult to implement standardized technical solutions, highlighting a gap between available technical knowledge and the practical needs of road management and social welfare.

Consequently, although the relevance of this problem is recognized, few studies address the influence of collapse potential on the design of reinforced concrete pavements, revealing a gap in the scientific and technical literature. The absence of design methods that integrate specific criteria for collapsible soils has led to empirical solutions that, while effective in certain cases, do not guarantee optimal long-term structural performance.

In this context, this study seeks to contribute to scientific and technological knowledge in pavement engineering and soil mechanics through a detailed analysis of the interaction between collapse potential and optimal sizing of RCC on urban roads in Huancayo. The results will be useful for engineers, urban planners, and infrastructure managers, facilitating the optimization of design and construction criteria that ensure stability and extend service life under adverse geotechnical conditions. At the national level, various studies have shown collapsible soils in coastal and jungle areas, causing problems for the durability of urban pavements and roads. In areas such as Pisco, La Joya, Lambayeque, and Ventanilla, deposits with low natural density and high porosity have been identified, making them highly susceptible to collapse under load and saturation. Although controlled compaction can reduce this susceptibility, it does not completely eliminate it, especially in areas affected by intense cycles of humidity and dryness (López et al., 2022). Additionally, Castillo & Reyes (2024) point out that the lack of integration of collapsibility parameters in the National Building Regulations has favored inefficient empirical solutions, increasing maintenance costs and shortening the useful life of road infrastructure.

Huancayo is a critical case due to its unique combination of geological and climatic factors that influence the collapsibility of its urban soils. The region features alluvial deposits and soils with high void levels that, when saturated by seasonal rainfall, generate differential settlements that significantly affect pavement performance. Luque et al. (2020) warn that this problem not only compromises the durability of RCCs but also has significant social and economic impacts, as road failures affect mobility, increase transportation costs, and limit urban development.

Therefore, the lack of methodologies that integrate soil-pavement interaction into RCC design highlights the urgent need for technical proposals that optimize the thickness, structural elasticity, and stability of urban roads in Huancayo. This study aims to evaluate the social impact of failures in RCC pavements located on collapsible soils in the city, to establish criteria that ensure the durability, functionality, and sustainability of road infrastructure under adverse geotechnical conditions. It also seeks to analyze the perceptions and impacts on mobility and costs for users of roads such as José Carlos Mariátegui Avenue, San Carlos Avenue, Progreso Avenue, Ferrocarril Avenue, Jacinto Ibarra Avenue, Huancavelica Avenue, Coronel Santibáñez Avenue, Circunvalación Avenue, Independencia Avenue, and Cantuta Avenue in Huancayo.

Methodology

This study is descriptive and has a correlational approach. Data were collected on social perceptions, mobility impacts, costs, and safety of users traveling on roads with pavement defects. The study population consisted of citizens who regularly travel on urban roads located on collapsible soils in the selected sections.

For this population, a stratified probability sampling was applied, based on vehicular and pedestrian flow in each evaluated section. The total sample comprised 250 citizens, distributed proportionally according to the approximate volume of users in each section, in order to adequately represent the diversity of experiences and perceptions. Table 1 below presents the detailed distribution of the sample by road and section:

Table 1

Distribution of the selected sample

Road	Section	Assigned Users (Pedestrians)
Av. José Carlos Mariátegui	AV. Ferrocarril-Av. Circunvalación	25
Av. San Carlos	Jr. San Judas Tadeo - Jr. Santa Cecilia	25
Av. Progreso	AV. Ferrocarril-Av. Mariscal Castilla	25
Av. Ferrocarril	AV. Evitamiento - Av. Circunvalación	25
Av. Jacinto Ibarra	AV. Leoncio Prado-Av. Próceres	25
Av. Huancavelica	Av. Cantuta - Av. Evitamiento	25
Av. Coronel Santibáñez	Jr. Gálvez - Jr. San Agustín	25
Av. Circunvalación	Av. Giráldez - Av. Ocopilla	25

Av. Independencia	AV. Mantaro-Av. Huancavelica	25
Av. Cantuta	AV. Huancavelica-Av. Mariscal Castilla	25

Among the data collection instruments and techniques, questionnaires were administered in person and digitally to users of the selected roads, using platforms such as Google Forms for those with greater technological proficiency. The variables considered included perceptions of road safety, the impact on travel time and transportation costs, satisfaction with the road infrastructure, and frequency of use of each road.

Additionally, a comprehensive record and analysis of technical defects in the pavement of the selected sections was conducted to correlate the perceived social impact with the severity of the observed damage.

Data analysis was carried out using inferential statistics to characterize the sample and the main variables. Spearman's Rho bivariate correlations were used, due to the nonparametric nature of the data, to determine the relationship between social variables and technical characteristics. A multivariate analysis was also performed to identify the main predictors of social impact. Finally, the study was complemented with a structural equation model that clearly exposes the theoretical and causal relationships between variable 1 and the indicators that make up variable 2.

Results

Table 2
Bivariate correlation (Spearman's Rho)

Correlations				
			V1	**V2**
Spearman's Rho	V1	Correlation Coefficient	1,000	,506**
		Significance bilateral	.	,010
		N	250	250
	V2	Correlation Coefficient	,506**	1,000
		Significance bilateral	,010	.
		N	250	250
****Correlation is significant at the 0.01 level (Bilateral)**				

Analysis:

- Spearman's rho coefficient of 0.506 reflects a moderate positive association between variables V1 and V2, indicating that as one variable increases, the other tends to increase significantly.
- The bilateral significance level ($p = 0.01$) is less than 0.05, making the result statistically significant, demonstrating that the observed relationship is not due to chance.
- Consequently, it can be inferred that the technical characteristics of the pavement and soil (V1) are linked to the measured social impact (V2). In practical terms, a greater potential for collapse or technical deterioration leads to a higher social impact, manifested in longer travel times, higher costs, and unsafe road conditions.
- Furthermore, the considerable sample size (250 users) strengthens the robustness and reliability of this association, especially in the urban context of Huancayo.

Table 3
Correlation coefficient

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Desv. Error	Beta		
1	(Constant)	27,692	1,091		25,387	,000
	p15	-,075	,287	-,061	-,262	,796
	p16	,585	,304	,439	1,922	,068
	p17	,313	,180	,340	1,739	,097
a. Dependent variable: V1						

Based on Table 2, which presents the multiple regression analysis, the following analysis can be described in relation to the technical characteristics and their social impact:

- The dependent variable corresponds to the social impact of the pavement, identified as (V1).
- The indicators of the technical characteristics of the pavement and soil (V2) are the responses to technical questions Q15, Q16, and Q17, which are detailed below:

- Q15: adaptation to stresses/elasticity
- Q16: thickness adequacy
- Q17: knowledge of geotechnical characteristics

Interpretation of the coefficients:

Constant = 27.692 ($p < 0.001$)

- This value represents the basis of the social impact without considering the effects of the independent variables.

P15: Coefficient = -0.075, p = 0.796

- The negative coefficient suggests that significant deformations associated with low elasticity tend to decrease the social impact. However, given the high p-value (greater than 0.05), this effect is not statistically significant and could be considered irrelevant.

P16: Coefficient = 0.585, p = 0.068

- The positive and moderate coefficient indicates that greater perception of thickness adequacy is associated with an increase in reported social impact. The p-value, close to the typical threshold of 0.05, indicates a marginally significant effect that could be relevant in larger samples.

P17: Coefficient = 0.313, p = 0.097

- This positive coefficient indicates that greater knowledge of geotechnical characteristics is associated with greater perceived social impact. The p-value suggests a positive trend relevant to be considered in future analyses.

Conclusion:

- Although none of the indicators reached conventional statistical significance ($p < 0.05$), the trends observed in P16 and P17 merit attention and complementary analysis in future research.

- Perception of pavement thickness and local geotechnical knowledge could serve as moderate predictors of social impact.
- The indicator related to low-elasticity deformations does not appear to directly influence social perception, as it is a more technical and specific aspect.

Figure 1
Structural equation generated with SmartPLS software

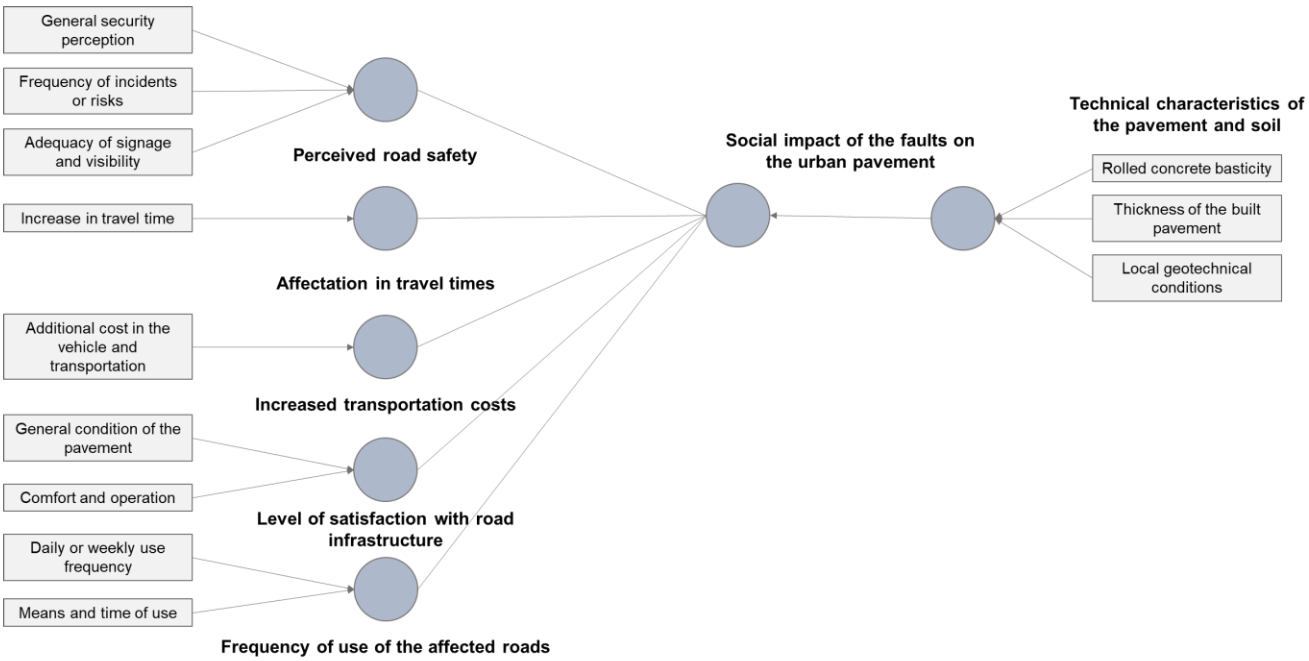

Figure 1 shows the technical characteristics of the pavement and soil within a structural equation model, analyzed using SmartPLS software. This model visualizes how these characteristics directly influence the social impact caused by urban pavement failures. This impact, in turn, impacts various social dimensions. Thus, the model quantitatively validates that improving elasticity, ensuring adequate thickness, and considering local geotechnical conditions are fundamental factors in minimizing the social impact associated with failures on urban roads in Huancayo.

Discussion

After analyzing the results obtained in this research, a close relationship is confirmed between the independent variable—the technical conditions of the pavement—and its indicators: adequate thickness, elasticity, and geotechnical stability, and the dependent variable, which is the social impact derived from failures in urban pavements in Huancayo. The moderate positive correlation observed (Rho = 0.506; p = 0.01) reveals that deterioration related to soil collapse increases travel times, affects road safety, and increases risks and costs, in addition to decreasing citizen satisfaction and road use frequency.

These findings are consistent with previous research, such as that of Alcalá et al. (2023), which documents how damage to deteriorated road infrastructure negatively impacts mobility and quality of life for users in similar urban contexts. Furthermore, the multivariate analysis highlighted the importance of adequate pavement thickness and knowledge of soil characteristics as relevant predictors of social impact. This is directly related to the studies by Castillo & Reyes (2024) and López et al. (2022), which underscore the need for accurate geotechnical parameters to extend pavement durability and effectiveness.

On the other hand, the lack of statistical significance in the perception of elasticity (P15) with respect to social impact is based on technical evidence suggesting that this variable may be less noticeable to users compared to other more visible indicators, such as surface damage or deterioration (Akhnoukh et al., 2025). Finally, the validation of the structural model using SmartPLS software reinforces the regression results and suggests a robust integration of technical and social variables within a rigorous statistical framework, as recommended by the literature on structural modeling in civil engineering (Ortega, 2015).

Conclusions

It can be stated that the behavior of failures in urban roads on collapsible soils generates a significant social impact on citizens who travel through the selected sections in Huancayo. Furthermore, it was confirmed that the technical characteristics of the pavement, particularly adequate thickness and local geotechnical conditions, are moderate predictors of social impact, which manifests itself in road insecurity, increased travel times and costs, dissatisfaction with the infrastructure, and decreased frequency of use of the affected roads.

Furthermore, the statistical results showed a significant relationship between the technical conditions of the pavement and soil, social perceptions, and the effects observed on users. This underscores the importance of prioritizing key technical criteria to mitigate negative impacts in these environments. Although the perception of structural elasticity did not show a significant influence on social impact, adequate structural designs and a thorough understanding of geotechnical behavior are essential, as these aspects should not be underestimated when planning road interventions on the roads studied.

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