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Mejorando la estabilidad estructural en caminos rurales con la viga Benkelman: un estudio de caso en el Perú

Enhancing structural stability in rural roads with the Benkelman beam: a case study in Peru

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Abstract

This study evaluates the granular subbase of the Oyon Ambo road in Pasco, Peru, using the Benkelman Beam test, covering from km 181+000 to km 230+000. The non-destructive methodology allowed for measuring pavement deflections under static loads, identifying critical areas that require improvements. Laboratory analyses included granulometric analysis, natural moisture, Atterberg limits, Modified Proctor, and CBR to characterize soil properties. Results indicated that the granular subbase is generally in good condition, with average deflections below admissible limits. However, higher deflections were observed in the critical section between Km 198+180 and Km 198+580, suggesting the need for specific interventions. Recommended measures include additional compaction, replacement of expansive soils, and drainage improvement. This approach provides a solid foundation for future interventions and road conservation strategies, promoting the safety and functionality of the road infrastructure in the Pasco region.

Keywords: Granular Sub-base, Benkelman Beam, Pavement Deflections, CBR.

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1. INTRODUCTION

The structural integrity and longevity of rural road infrastructure are pivotal for regional connectivity and economic development. This study focuses on evaluating the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road using the Benkelman Beam test. This road section, spanning from km 181+000 to km 230+000, plays a crucial role in facilitating the transport of people and goods between neighboring communities, particularly in regions with challenging climatic conditions.

Globally, roads are essential for socioeconomic growth, and their performance hinges on their ability to sustain commercial traffic over their design life. In Peru, the road network is divided into three levels: National, Departmental, and Local. The National Road Network comprises over 27,000 km of paved roads, while most of the Departmental and Local Road Networks consist of unpaved roads, highlighting the need for continuous maintenance and evaluation to ensure functionality and safety.

The Dv. Cerro de Pasco – Dv. Chacayan road is a critical segment within the Pasco region's infrastructure, serving as the main conduit for agricultural and commercial transport. However, adverse climatic conditions such as constant rainfall have caused stability problems in the granular subbase (Ariza Flores & Salvador, 2024), necessitating this study. The structural evaluation using the Benkelman Beam measures pavement deflections under static loads, providing crucial data for diagnosing the road's condition and planning improvements (Sanjay et al., 2022).

Non-destructive testing (NDT) methods like the Benkelman Beam have gained prominence due to their efficiency and reliability. The Benkelman Beam test, developed by engineer A. C. Benkelman in 1953, is a widely recognized methodology for assessing the structural capacity of pavements (Jain et al., 2023). This device measures the elastic deformation of a road structure under an applied load, allowing for the identification of critical areas and deficiencies in the granular subbase (Markó et al., 2013). The non-destructive testing methodology employed by the Benkelman Beam is quick, economical, and does not affect the pavement structure (Prabhu et al., 2021), making it ideal for studies like the present one, as well as it was used in other similar cases (Adigopula et al., 2022; Handayani et al., 2023).

A comparative study by (Guzzarlapudi et al., 2016) highlights the effectiveness of the Benkelman Beam and Lightweight Deflectometer (LWD) in evaluating subgrade moduli on low volume roads. The study found that while static moduli values measured by the Benkelman Beam are generally lower than dynamic moduli values measured by the LWD, both methods provide reliable data with good correlation between static and dynamic moduli. This reinforces the value of using the Benkelman Beam for detailed structural evaluations.

The general objective of this study is to structurally analyze the granular subbase of the aforementioned road section using the Benkelman Beam test. Specific objectives include determining deflections in the granular subbase, identifying admissible deflection values, and proposing solutions for deficiencies found in critical areas. This evaluation will provide essential data on the road's condition, which can be used to present road conservation proposals to relevant authorities and improve the road's safety and functionality.

The research justification is multifaceted. Theoretically, it seeks to understand and document the structural condition of the road, providing a scientific basis for future evaluations and improvements. Practically, the study will enable informed interventions to enhance the load-bearing capacity of the granular subbase, resulting in greater road durability and safety. Methodologically, it aims to demonstrate the efficacy of the Benkelman Beam test as a structural evaluation tool in the Peruvian context. Economically, proper road maintenance will not only reduce long-term repair costs but also improve local transport and economy. Socially, road improvement will reduce accident risks, facilitating safe and efficient transport for the region's inhabitants.

In light of the comprehensive review by (Dwivedi & Suman, 2023) and the comparative analysis by (Guzzarlapudi et al., 2016) this study aims to contribute similarly valuable insights for the Peruvian context. The Benkelman Beam test's ability to measure elastic deformation and diagnose structural deficiencies aligns with the objectives of enhancing pavement quality and durability, ensuring timely and efficient road maintenance.

This research requires mixed evaluation techniques which are very frequent in engineering (Paniura et al., 2023). This study addresses a critical issue in the road infrastructure of the Pasco region through a detailed and methodologically robust evaluation of the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road. The expected results will significantly contribute to the knowledge of road management and maintenance under adverse conditions, providing a roadmap for future interventions and improvements in the regional road network.

2. RESULTS ANALYSIS

1.1 Data Collection and Presentation

Direct observations were used to collect data during road platform inspections and the Benkelman Beam test. Data from equipment dials and laboratory tests on platform samples were used to determine improvement heights in critical areas between kilometers 198+000 and 199+000. Dial readings from the Benkelman Beam test were crucial for analyzing the behavior of the granular subbase and establishing necessary improvement heights. Spreadsheet analysis applied criteria such as admissible load, expansive soils, and low bearing capacity (AASHTO 93).

Field data collected during the Benkelman Beam test were processed in spreadsheets with necessary corrections to ensure data accuracy. Detailed analysis identified patterns and trends in material behavior, allowing for an accurate evaluation of granular subbase conditions and their implications for pavement structure. Final results are shown in Table 1.

Table 1.

Deflectometric result from 198+040 to 198+240

Progressive (km)	Readings (10^{-2}mm)		Uncorrected Deflections (10^{-2}mm)		DEFLECTOMETRIC RESULTS		Bend radius	Meets
					Fixed deflections			
	L_{25}	L_{max}	D_0	D_{25}	D_0 x 10^{-2}mm	D_{25} x 10^{-2}mm		
198+040	8	16	64	32	64	32	98	OK
198+060	6	12	48	24	48	24	130	OK
198+080	6	11	44	20	44	20	130	OK
198+100	13	17	68	16	68	16	60	OK
198+120	9	19	76	40	76	40	87	OK
198+140	10	20	80	40	80	40	78	OK
198+160	9	14	56	20	56	20	87	OK
198+180	11	15	60	16	60	16	71	OK
198+200	8	15	60	28	60	28	98	OK
198+220	7	16	64	36	64	36	112	OK
198+240	8	14	56	24	56	24	98	OK

1.2 Laboratory Analysis

After obtaining laboratory results and identifying the stratigraphic profile of the area to be intervened, a detailed summary table of tests conducted on extracted samples was prepared. This table's main objective was to compile and organize all obtained test information, providing a clear and precise view of soil characteristics. These data enabled a well-founded determination of necessary soil improvement heights. The table specified test results and used parameters, crucial for ensuring optimal and efficient soil improvement work.

1.3 Deflectometric Results

The analysis of results obtained from the Benkelman Beam test on the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road focuses on evaluating measured deflections in various study segments. During the Benkelman Beam test, deflection measurements were conducted in several critical road segments.

For the segment between Km 197+140 and Km 197+700 L/D, the following notable results were obtained: the average deflections were 47.31 mm/100, with a minimum of 24.00 mm/100 and a maximum of 76.00 mm/100. The recorded standard deviation was 12.65 mm/100, and the characteristic deflection was calculated at 63.76 mm/100. The admissible deflection for this segment is 99.00 mm/100 as shown in Table 2.

Table 2.

Deflectometric results from 197+140 to 197+700

Progressive (km)	Readings (10^{-2}mm)		Uncorrected Deflections (10^{-2}mm)		DEFLECTOMETRIC RESULTS		Bend radius	Meets
					Fixed deflections			
	L_{25}	L_{max}	D_0	D_{25}	D_0 x 10^{-2}mm	D_{25} x 10^{-2}mm		
197+140	10	12	48	8	48	8	78	OK
197+160	8	14	56	24	56	24	98	OK
197+180	7	12	48	20	48	20	112	OK
197+200	7	12	48	20	48	20	112	OK
197+220	7	12	48	20	48	20	112	OK
197+240	5	10	40	20	40	20	156	OK
197+260	7	12	48	20	48	20	112	OK
197+280	9	20	80	44	80	44	87	OK
197+300	8	14	56	24	56	24	98	OK
197+320	9	18	72	36	72	36	87	OK
197+340	7	12	48	20	48	20	112	OK
197+360	7	12	48	20	48	20	112	OK
197+380	6	13	52	28	52	28	130	OK
197+400	7	12	48	20	48	20	112	OK
197+420	7	12	48	20	48	20	112	OK
197+440	7	12	48	20	48	20	112	OK
197+460	7	12	48	20	48	20	112	OK
197+480	7	12	48	20	48	20	112	OK
197+500	7	12	48	20	48	20	112	OK
197+520	7	12	48	20	48	20	112	OK
197+540	7	12	48	20	48	20	112	OK
197+560	7	12	48	20	48	20	112	OK
197+580	7	12	48	20	48	20	112	OK
197+600	7	12	48	20	48	20	112	OK
197+620	7	12	48	20	48	20	112	OK
197+640	7	12	48	20	48	20	112	OK
197+660	7	12	48	20	48	20	112	OK
197+680	7	12	48	20	48	20	112	OK
197+700	7	12	48	20	48	20	112	OK

For the segment between Km 197+140 and Km 197+700 L/I, the following notable results were obtained: the average deflections were 55.54 mm/100, with a minimum of 36.00 mm/100 and a maximum of 88.00 mm/100. The recorded standard deviation was 10.14 mm/100, and the characteristic deflection was calculated at 68.72 mm/100. The admissible deflection for this segment is 99.00 mm/100.

Table 3.

Deflectometric results from 197+170 to 197+730

Progressive (km)	Readings (10^{-2}mm)		Uncorrected Deflections (10^{-2}mm)		DEFLECTOMETRIC RESULTS Fixed deflections		Bend radius	Meets
	L_{25}	L_{max}	D_0	D_{25}	D_0 x 10^{-2}mm	D_{25} x 10^{-2}mm		
197+170	7	14	56	28	56	28	112	OK
197+190	7	13	52	24	52	24	112	OK
197+210	6	12	48	24	48	24	130	OK
197+230	6	12	48	24	48	24	130	OK
197+250	16	25	100	36	100	36	49	OK
197+270	10	15	60	20	60	20	78	OK
197+290	6	9	36	12	36	12	130	OK
197+310	7	12	48	20	48	20	112	OK
197+330	8	12	48	16	48	16	98	OK
197+350	8	12	48	16	48	16	98	OK
197+370	5	9	36	16	36	16	156	OK
197+390	7	10	40	12	40	12	112	OK
197+410	5	10	40	20	40	20	156	OK
197+430	10	13	52	12	52	12	78	OK
197+450	14	26	104	48	104	48	56	OK
197+470	11	22	88	44	88	44	71	OK
197+490	6	15	60	36	60	36	130	OK
197+510	5	9	36	16	36	16	156	OK
197+530	6	12	48	24	48	24	130	OK
197+550	6	12	48	24	48	24	130	OK
197+570	5	10	40	20	40	20	156	OK
197+590	6	12	48	24	48	24	130	OK
197+610	5	10	40	20	40	20	156	OK
197+630	10	19	76	36	76	36	78	OK
197+650	6	12	48	24	48	24	130	OK
197+670	8	15	60	28	60	28	98	OK
197+690	8	12	48	16	48	16	98	OK
197+710	5	11	44	24	44	24	156	OK
197+730	5	10	40	20	40	20	156	OK

In the section between Km 197+720 and Km 198+160 L/D, the following notable results were obtained: the average deflection was 54.26 mm/100, with a minimum of 40.00 mm/100 and a maximum of 80.00 mm/100. The recorded standard deviation was 10.29 mm/100, and the characteristic deflection was calculated at 67.64 mm/100. The admissible deflection for this section is 99.00 mm/100.

Table 4.

Deflectometric results from 197+720 to 198+160

Progressive (km)	Readings (10^{-2}mm)		Uncorrected Deflections (10^{-2}mm)		DEFLECTOMETRIC RESULTS Fixed deflections		Bend radius	Meets
	L_{25}	L_{max}	D_0	D_{25}	D_0 x 10^{-2}mm	D_{25} x 10^{-2}mm		
197+720	7	12	48	20	48	20	112	OK
197+740	7	12	48	20	48	20	112	OK
197+760	7	12	48	20	48	20	112	OK
197+780	7	12	48	20	48	20	112	OK
197+800	7	12	48	20	48	20	112	OK
197+820	10	15	60	20	60	20	78	OK
197+840	6	12	48	24	48	24	130	OK
197+860	7	14	56	28	56	28	112	OK
197+880	7	13	52	24	52	24	112	OK
197+900	6	13	52	28	52	28	130	OK
197+920	9	19	76	40	76	40	87	OK

197+940	10	20	80	40	80	40	78	OK
197+960	7	17	68	40	68	40	112	OK
197+980	6	12	48	24	48	24	130	OK
198+000	6	13	52	28	52	28	130	OK
198+020	6	12	48	24	48	24	130	OK
198+040	6	13	52	28	52	28	130	OK
198+060	5	10	40	20	40	20	156	OK
198+080	7	14	56	28	56	28	112	OK
198+100	7	14	56	28	56	28	112	OK
198+120	6	12	48	24	48	24	130	OK
198+140	8	16	64	32	64	32	98	OK
198+160	11	22	88	44	88	44	71	OK

1.4 Analysis of the data obtained

Results obtained show variability in measured deflections across different road segments. Generally, average deflection values are below admissible deflections, indicating that the granular subbase is in acceptable condition in most evaluated segments. However, some critical areas with higher deflection values were identified, particularly in the critical sector between Km 198+180 and Km 198+580.

The section between Km 197+140 and Km 197+700 in both lanes presents an average deflection of 47.31 mm/100 in the right lane and 55.54 mm/100 in the left lane. These values are significantly below the admissible deflection of 99.00 mm/100, suggesting that the granular subbase in this section has good load-bearing capacity.

Fig. 1. Sector deflections Km. 197+140 – Km. 197+700 L/D

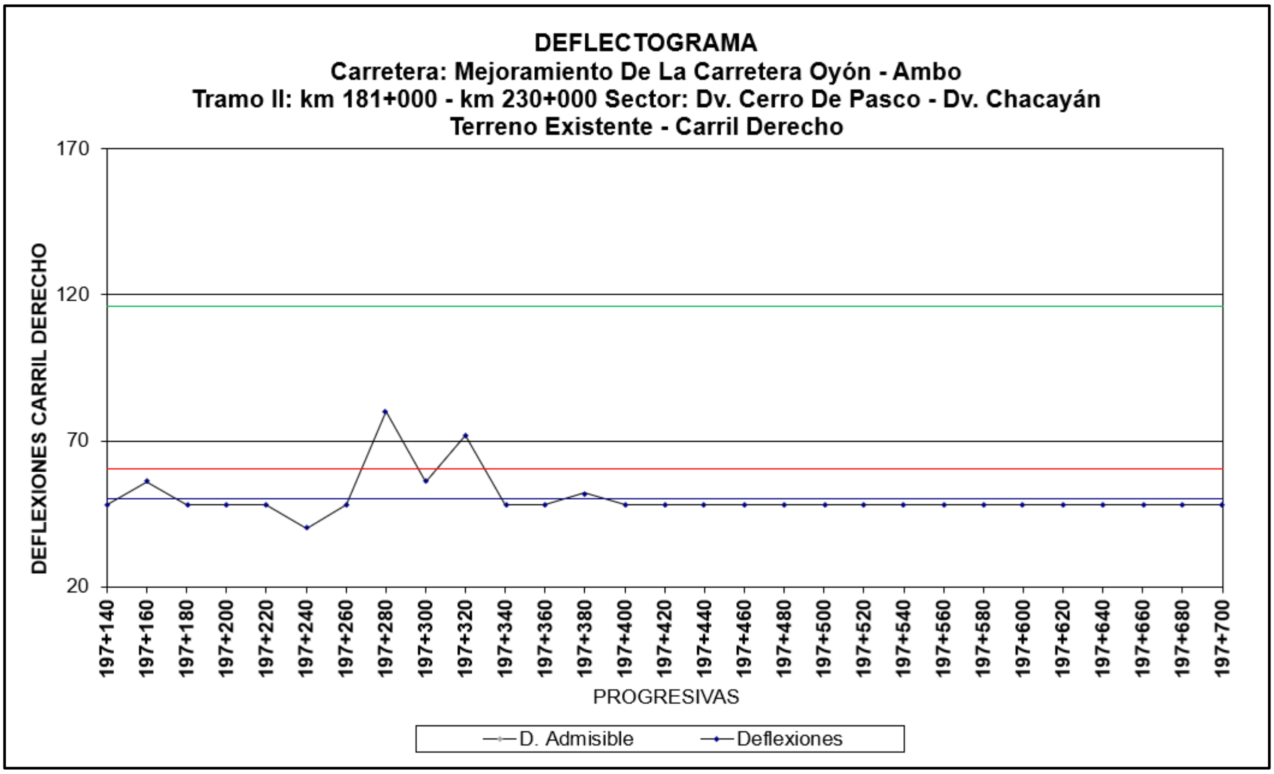
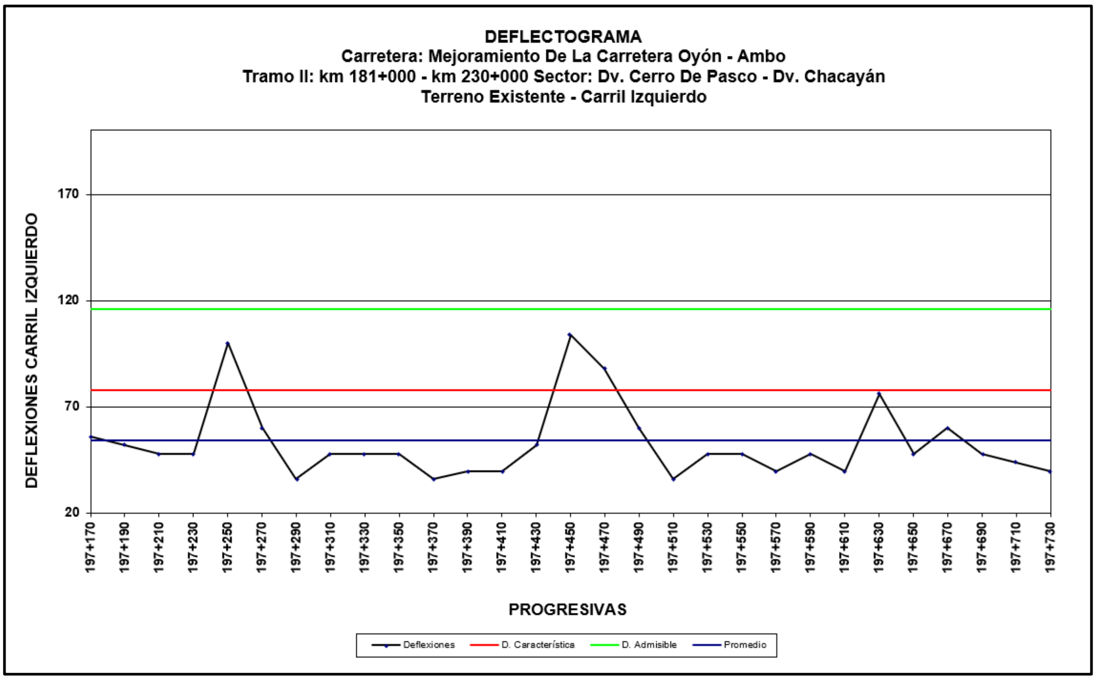
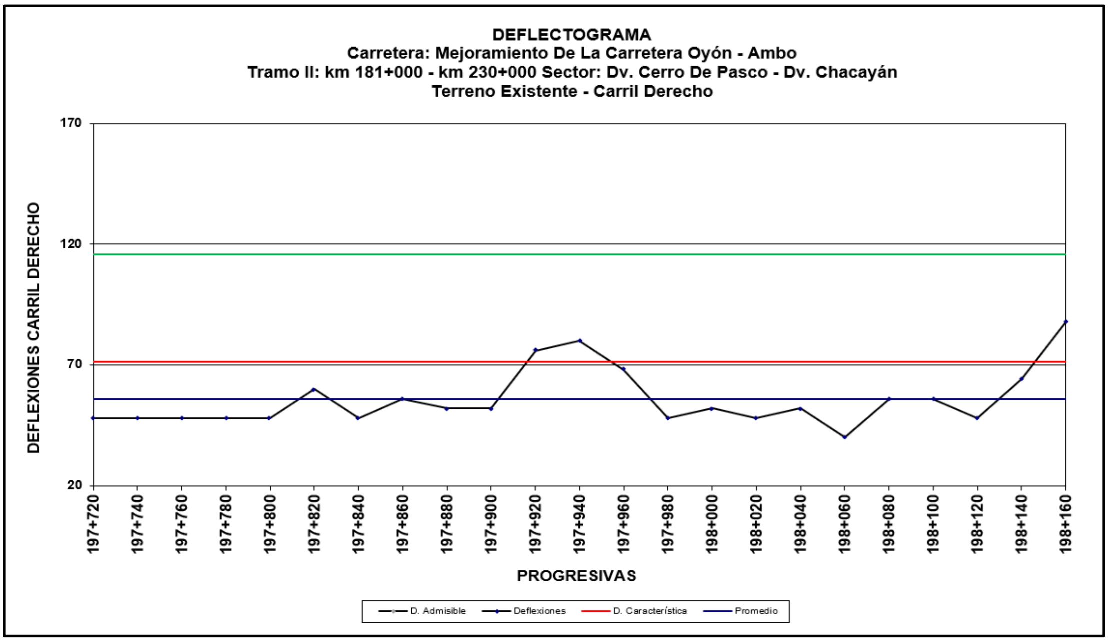


Fig. 2. Sector deflections Km. 197+170 – Km. 197+730 L/I



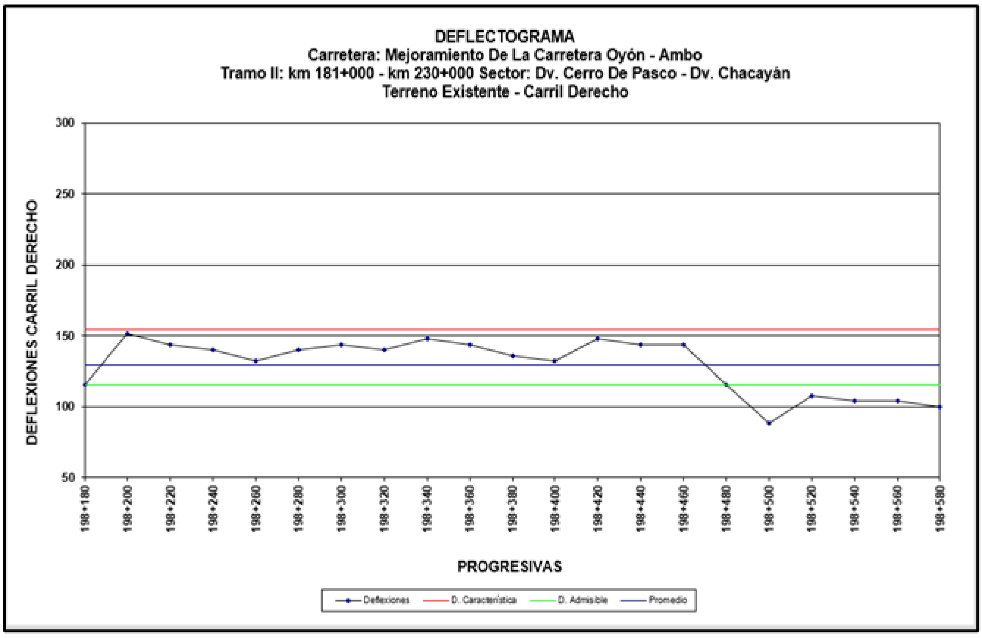
In the section between Km 197+720 and Km 198+160, the deflection values are also below the admissible deflection, with averages of 54.26 mm/100 and 54.00 mm/100 for the right and left lanes, respectively. These results reinforce the conclusion that the granular subbase in these sections is in good condition.

Fig. 3. Sector deflections Km. 197+170 – Km. 197+730 L/I



However, in the critical sector between Km 198+180 and Km 198+580, higher deflections were observed. The right lane presented an average of 62.48 mm/100 and the left lane 66.10 mm/100, with characteristic deflections of 73.32 mm/100 and 80.49 mm/100, respectively. Although these values are still below the admissible deflections of 99.00 mm/100 and 116.00 mm/100, they indicate greater deformation in the granular subbase, suggesting the need for specific interventions to improve its load-bearing capacity.

Fig. 4. Sector deflections Km. 198+180 – Km. 198+580 L/D



The results of the Benkelman Beam test indicate that, in general, the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road is in good condition, with some critical sections that could benefit from improvement measures. This analysis provides a solid foundation for planning future interventions and properly managing road conservation in this important transport artery.

1.5. Deflectometric Evaluation in the Granular Subbase

For the deflectometric evaluation, the Benkelman Beam equipment and a beam truck with the following characteristics were used: vehicle classification C2, load weight on the rear axle of 8200 kg, rear axle tires of 10 x 20, and inflation pressure of 552 Kpa (5.6 kgf/cm² or 80 PSI). With all equipment calibrated and the beam truck adjusted, the Benkelman Beam test was conducted on the granular subbase layer. Deflection was measured every 20 meters, evaluating even positions on the right lane and odd positions on the left lane. Subsequently, readings from the dials were corrected in an Excel format to determine if soil improvement in the critical sector benefited the structural behavior of the granular subbase.

Tabla 5.

Deflectometric result in granular sub-base from 198+180 to 198+580

Progressive (km)	Readings (10^{-2}mm)		Uncorrected Deflections (10^{-2}mm)		DEFLECTOMETRIC RESULTS Fixed deflections		Bend radius	Meets
	L_{25}	L_{max}	D_0	D_{25}	D_0 x 10^{-2}mm	D_{25} x 10^{-2}mm		
198+180	8	15	60	28	60	28	98	OK
198+200	7	16	64	36	64	36	112	OK
198+220	8	14	56	24	56	24	98	OK
198+240	9	15	60	24	60	24	87	OK
198+260	8	14	56	24	56	24	98	OK
198+280	10	19	76	36	76	36	78	OK
198+300	9	15	60	24	60	24	87	OK
198+320	8	16	64	32	64	32	98	OK
198+340	9	17	68	32	68	32	87	OK
198+360	7	15	60	32	60	32	112	OK
198+380	6	13	52	28	52	28	130	OK
198+400	8	15	60	28	60	28	98	OK
198+420	6	11	44	20	44	20	130	OK
198+440	13	17	68	16	68	16	60	OK
198+460	9	19	76	40	76	40	87	OK

198+480	11	15	60	16	60	16	71	OK
198+500	8	16	64	32	64	32	98	OK
198+520	7	14	56	28	56	28	112	OK
198+540	10	20	80	40	80	40	78	OK
198+560	9	15	60	24	60	24	87	OK
198+580	8	17	68	36	68	36	98	OK

After obtaining corrections for even progressions in the right lane and odd progressions in the left lane of the platform, it was observed that the results are optimal and comply with the maximum admissible deflection calculated for the subgrade. Therefore, following the structural evaluation with the Benkelman Beam test, it is concluded that the improvement made in the critical sector is satisfactory and that the granular subbase is adequate.

4. DISCUSSION

This study provides a thorough evaluation of the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road using the Benkelman Beam test. The results indicate that, while most sections of the road show deflections within acceptable limits, there are critical areas with higher deflection values, indicating the need for specific interventions to improve the pavement's load-bearing capacity.

A prominent aspect of the study is the identification of critical zones, particularly the segment between Kilometers 198+180 and 198+580. This segment showed higher deflections compared to other road sections, recording averages of 62.48 mm/100 and 66.10 mm/100 for the right and left lanes, respectively. Despite being below the acceptable deflection limits of 99.00 mm/100 and 116.00 mm/100, respectively, these values are significantly higher than the averages observed in other sections, suggesting greater deformation in the granular subbase.

The variability in deflectometric results can be attributed to various factors such as soil geotechnical conditions, the presence of expansive soils, and compaction variations during construction. Laboratory analyses on collected soil samples confirmed the presence of soils with expansive potential in some critical sections. These soils can retain water molecules in their structure, causing volume changes and negatively affecting pavement stability. Liquidity and consistency indices obtained from Atterberg limits tests also indicate the presence of soils that may behave plastically or liquid under certain moisture conditions, contributing to the observed greater deformation.

Comparative studies, such as those by (Guzzarlapudi et al., 2016) have shown that while the Benkelman Beam provides reliable static moduli values, these are generally lower than dynamic moduli values measured by Lightweight Deflectometer (LWD). This suggests that the Benkelman Beam, while effective, might benefit from being complemented by dynamic testing methods for a more comprehensive evaluation. The correlation between static and dynamic moduli values indicates that using both methods could provide a more robust assessment of the subgrade's condition.

Furthermore, the study highlights the importance of using non-destructive testing (NDT) methods like the Benkelman Beam in road infrastructure management. The quick and economical nature of the Benkelman Beam test makes it suitable for routine evaluations, ensuring timely identification and remediation of structural deficiencies. This is particularly important in regions with adverse climatic conditions that can exacerbate pavement deterioration.

The results of this study underline the necessity for targeted interventions in critical sections of the road. Recommendations include additional compaction of the granular subbase, replacement of expansive soils with higher quality materials, and improving drainage to reduce water accumulation. These measures are expected to enhance the pavement's load-bearing capacity, extend the road's service life, and reduce long-term maintenance costs.

5. CONCLUSION

This study on the structural evaluation of the granular subbase of the Dv. Cerro de Pasco – Dv. Chacayan road using the Benkelman Beam test has yielded important conclusions that will significantly contribute to improving the road infrastructure in the region. The results indicate that the granular subbase of the road is generally in good condition, with average deflections below admissible limits in most evaluated sections. However, critical areas with higher deflection values were identified, suggesting the need for specific interventions.

One of the most notable conclusions is the identification of the segment between Km 198+180 and Km 198+580 as a critical sector. This segment showed higher deflections than other road sections, although still within admissible limits. This variability in deflections can be attributed to the presence of expansive soils and particular geotechnical conditions of the soil in these areas. Detailed characterization of soil properties in these critical sections, including liquidity, consistency, and compressibility indices, confirmed the need for specific improvement measures.

The Benkelman Beam test has proven to be an effective and non-destructive tool for structural pavement evaluation. This method allowed for the precise identification of areas requiring immediate attention, providing valuable data for planning maintenance and improvement interventions. The ability to measure the elastic deformation of the pavement under a static load provides a clear view of the granular subbase's structural condition, facilitating informed decision-making.

Recommendations for improvement measures in critical sections include additional compaction of the granular subbase, replacing expansive soils with higher quality materials, and improving drainage to reduce water accumulation. These interventions will not only enhance the pavement's load-bearing capacity but also extend the road's service life and reduce long-term maintenance costs.

Moreover, this study has broader implications for road infrastructure management in other regions with similar geotechnical and climatic conditions. The methodology used can be replicated to evaluate and improve the road network in other contexts, providing a solid foundation for implementing more effective road conservation strategies.

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