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Structural Design of Roadbed and Pavement in Transition Section of Roads and Bridges

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Abstract: As the lifeline of social development, road and bridge projects are the main channel to realize resource transportation and economic circulation. Ensuring the quality of road and bridge project construction is crucial for the development of society, the economy, and people's livelihoods. This paper studies the design of roadbed pavement structures in road and bridge transition sections. It aims to provide technical references and significance for China's road and bridge engineering design and construction units, promoting scientific and standardized design in these actions. This will contribute to the safety and stable operation of road and bridge projects, offering effective technical support. Furthermore, it seeks to foster the sustainable and healthy development of China's road and bridge engineering on a macro level.

Keywords: Road and bridge transition section; Roadbed pavement structure design; Lap plate; Easing transition section; Drainage system

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1. Introduction

As society develops, the demand for road and bridge infrastructure is becoming increasingly diversified. Road and bridge engineering needs to be highly adaptable and functional to meet the multifaceted requirements of economic development and the improvement of people's livelihoods. Therefore, it is crucial to focus on enhancing the quality of design during the planning stage of road and bridge engineering. Meeting the demands of social development depends significantly on the design quality, particularly in the transition sections of roadbeds and pavements. The design of these sections directly impacts the overall construction quality of road and bridge projects. Only through a reasonable and refined design of roadbed pavement structures in transition sections can road and bridge engineering projects meet the quality requirements necessary for social development, effectively ensuring their success.

2. Importance of road and bridge transition section roadbed pavement design

The road and bridge transition section is an important part of connecting the roadbed and bridge section, and its

design quality occupies a vital position in the overall project.

Firstly, the rationality of road and bridge transition section design directly affects the stability and applicability of the overall structure of the project. In the road traffic operation stage, the transition section between the roadbed and the bridge junction must ensure a smooth transition due to the differing structural forms. This is necessary to avoid issues such as road surface unevenness and settlement problems caused by structural differences.

Secondly, the design of the road and bridge transition section significantly impacts road comfort and safety. An inappropriate design may cause vehicles to experience jumping and vibrations, increasing driving safety risks, particularly for high-speed vehicles on highways. Therefore, the transition section design must consider vehicle response to ensure a smooth driving surface.

Finally, the design should also account for economic and sustainability factors. The costs of construction and maintenance for the transition section should not be overlooked. A well-designed section can reduce material and labor costs, extend the service life of road and bridge projects, and lower long-term maintenance costs [1].

3. Road and bridge transition section of the roadbed pavement common issues

3.1. Uneven settlement produces steps

The transition section between the roadbed and bridge, as a structural connection node, often experiences uneven settlement due to its unique structural characteristics. This uneven settlement is a common issue in road and bridge engineering. It not only affects driving comfort and safety but also negatively impacts the long-term performance of the roadbed and bridge. Typically, uneven settlement results from differences in stiffness between the roadbed and bridge foundation. The roadbed soil is usually softer compared to the bridge foundation, which is relatively rigid. Vehicle loads and highway gravity can cause significant settlement in the roadbed, while the bridge foundation experiences minimal settlement. This discrepancy creates a noticeable height difference at the junction, leading to the formation of “steps.” Such discontinuities can cause driving vibrations, reduce comfort, and even lead to traffic accidents.

3.2. Depreciation problems lead to road and bridge issues

The road and bridge transition section of the roadbed pavement inevitably experiences depreciation over time and with frequent vehicle passage. This is a significant cause of road and bridge damage. Depreciation not only reduces the functionality of the transition section but may also seriously shorten its service life and increase maintenance costs. Depreciation problems typically manifest as material aging and wear. Transition sections are subjected to repetitive stresses from the vehicle wheel loads, causing material performance to gradually weaken. Asphalt pavements may develop cracks and potholes, while concrete pavements may experience spalling and cracking. In regions affected by climate change, high temperatures, low temperatures, and humidity variations further accelerate material aging and exacerbate depreciation issues, particularly when combined with uneven vehicle load distribution.

3.3. Excessive structures causing inconsistent bridge head step heights

In the transition section of road and bridge projects, an excessive number of structures such as bridge culverts and channels can lead to inconsistencies in the bridgehead step height. This phenomenon not only affects driving comfort and safety but may also result in more serious roadbed issues, impacting the service life of the road and bridge project. On one hand, as previously discussed, differences in structural stiffness between rigid elements like bridges, culverts, and passages, and the relatively softer roadbed can cause uneven settlement,

leading to noticeable steps. On the other hand, projects with numerous structures often involve complex hydrological environments. Bridges, culverts, and passages are typically located in areas where water flows converge, making them susceptible to water erosion, flood scouring, and changes in water level. If the drainage system is not properly designed, water accumulation during the rainy season can lead to roadbed settlement, further exacerbating the issue of varying bridge head step heights [2].

4. Road and bridge transition section roadbed pavement structure design points

4.1. Lap plate and non-lap plate design considerations

4.1.1. Lap plate design

In the road and bridge transition section roadbed pavement structure design, lap plate design is a key element. A well-designed lap plate not only addresses the issue of bridge bumpiness but also ensures driving comfort and safety. Firstly, the appropriate form of lap plate must be selected, which serves as the foundation for the design. Common forms of lap plates include single-sloping, double-sloping, and flat lap plates. Single-sloping lap plates are suitable for transition sections with significant settlement differences, as they help mitigate unevenness caused by settlement. Double-sloping lap plates are typically used in transition sections where settlement differences are minimal and provide more stability than single-sloping plates. Flat lap plates are appropriate for cases with minimal settlement and favorable foundation conditions but are less commonly used in practice.

Secondly, the length and width of the lap plate design should be determined based on specific engineering conditions. During the design stage, the length of the lap plate must account for the length of the gap reserved before placing the soil. The lap plate needs to span this gap to ensure that the filler settles properly and the plate effectively crosses the settlement zone, maintaining a smooth road surface. However, if the span length is too large, it may damage the original roadbed structure and prism. Typically, the length of the transition section for large bridges should be controlled between 8 to 12 meters, while for medium and small bridges, it should be set between 6 to 8 meters. Additionally, controlling the longitudinal slope change value of the lap plate is crucial in the transition section. The longitudinal slope change must meet the maximum allowable capacity value to ensure smooth and safe traffic flow. To ensure smoothness after settlement, the effective length of the lap plate must be adequately designed, considering all types of loads, including vehicle loads and its own weight, while leaving sufficient safety margins.

Finally, in the design of the lap plate width, it should be consistent with the width of the road surface to ensure continuity and safety. The design should ensure that the ratio of the short to long sides is greater than 2. Additionally, to facilitate road construction and subsequent maintenance, the edge of the lap plate should maintain a 0.5 m interval from the edge of the stone during the design phase. The design should also comply with the relevant technical parameters outlined in **Table 1**.

Table 1. Road and bridge transition section lap plate design technical parameters requirements

Parameters	Requirement	Parameter	Requirement
Length of large bridge overlap plate	8 m ~ 12 m	Length of bridge decks for small and medium-sized bridges	6 m ~ 8 m
Change in longitudinal slope after settlement	< Set maximum capacity value	Load considered at design stage	Vehicle Load, self-weight, safety margin
Slab width	The ratio of short and long sides ＞ 2	Edge to edge of curb spacing	0.5 m

4.1.2. Non-lap plate design

While the use of lap plates in transition sections offers significant advantages, there are also disadvantages. If a lap plate becomes damaged, it can lead to serious losses and require extensive, difficult maintenance. The root cause of bridge deck bumping issues lies in the rigidity differences between the bridge deck and the approach road. For transition sections without lap plates, it is crucial to ensure a proper rigid-to-flexible transition by using semi-rigid building materials. This approach has been widely practiced in road and bridge projects in Shaanxi Province, where practical results have demonstrated that this strategy effectively reduces the likelihood of settlement differences.

When applying a non-plate design, it is essential to enhance the drainage setup behind the platform and ensure that the compaction meets the prescribed standards. If the compaction base is inadequate, the soil's compression modulus has certain limitations. Even if soil compaction reaches 95%, its settlement may still exceed that of lime-stabilized soil. Therefore, the amount of soil used in the roadbed design should be carefully controlled [3].

4.2. Design points for gentle transition sections

The design of the gentle transition section of road and bridge transition section roadbed pavement focuses on several keys, subgrade treatment, filler section, structural layer design, and pavement elevation design [4].

Firstly, subgrade treatment is the primary concern in the design of gentle transition sections. The subgrade must be adequately compacted and stabilized to ensure its bearing capacity and stability meet the requirements. Typically, foundation reinforcement can be achieved through methods such as strong tamping, replacement, or mixing piles to minimize settlement and displacement.

Secondly, the selection of fillers for the gentle transition section significantly impacts the performance of the road base [5]. During the design phase, fillers with good gradation and superior compaction properties, such as crushed stone and gravel, should be chosen to ensure that the durability and bearing capacity of the roadbed. Therefore, during the construction design phase, it is crucial for the construction unit to strictly control the quality of the filler and the paving thickness, ensuring that compaction is performed in layers and that each layer's thickness aligns with design specifications.

Thirdly, in the structural layer design phase, it is essential to account for stress changes in the gentle transitions section and to adopt a reasonable combination of different materials and structural levels to facilitate a smooth transition between the bridge deck and the roadbed. During implementation, a high-strength semi-rigid base layer, such as cement-stabilized crushed stone combined with an asphalt layer, should be used to form a composite structure. This approach not only effectively disperses vehicular loads but also reduces the impact of settlement differences and enhances the overall stability of the gentle transition section.

Finally, pavement elevation design is a critical technical aspect of the gentle transition section. The road surface elevation must be carefully adjusted to ensure a smooth transition between the road and the bridge, avoiding the risk of vehicles "jumping" at the bridgehead due to sudden elevation changes. During the design phase, designers should carefully consider the elevation changes across different road sections and implement a gradual transition to ensure a smooth connection [6].

4.3. Key points of bridge abutment back design

Typically, the back of the bridge abutment primarily employs geotechnical barrier technology. During the design stage, the first key point is the selection and arrangement of geogrid. The design team should choose the appropriate geogrid materials, such as plastic, glass fiber, or polyester grating, based on specific engineering needs. It is essential to ensure that the geogrid possesses high strength and durability. The laying direction and

the number of geogrid layers should be determined according to the actual conditions. Horizontal laying is generally effective in improving the stability of the fill and shear strength. During installation, the construction team must ensure that the geotechnical barrier is smooth and tau to avoid wrinkles and slack.

Secondly, the selection of backfill material is crucial [7]. Quality, well-graded fillers such as medium-coarse sand, gravel, and well-graded aggregate should be used. Backfill compaction must meet the design standard, and the construction unit should fill in layers, with each layer's thickness not exceeding 20 cm to 30 cm. Layer-by-layer should be employed to ensure compaction and uniformity, with a compaction rate of ≥ 95%.

Thirdly, during the bearing capacity design stage, the design team must thoroughly consider the load distribution characteristics of the abutment back area to ensure that the bearing capacity meets the design requirements. Geocells within the backfill primarily enhance the tensile strength of the filler and help distribute the load. Therefore, during the design phase, the tensile strength and ductility of the geogrid should be taken into account to improve the overall structural stability.

Finally, for the interface processing design, the joints between the bridge deck and the roadbed should use flexible transition buttresses to mitigate the stiffness differences between materials. The combined effect of the geogrid and filler should effectively alleviate stress concentration issues caused by load changes and foundation deformation [8].

4.4. Road and bridge drainage system design points

The road and bridge transition section, which connects the bridge and the roadbed, is a critical area where the drainage system's design plays a vital role in ensuring long-term stability and performance.

Firstly, the overall layout of the transition section's drainage system should be scientific and reasonable. The design team needs to consider both horizontal and vertical drainage effectiveness while ensuring the smooth flow and capacity of the drainage pipes. The longitudinal drainage system is typically arranged along the center and sides of the roadbed, with drainage gradients set to effectively reduce water accumulation. The horizontal drainage system, which includes side ditches, drainage blind ditches, and horizontal drainage pipes, must ensure that water is quickly discharged during the rainy season [9].

Secondly, the design of the drainage system should include a reasonable road cross slope and longitudinal slope to ensure that surface water is quickly discharged into the side ditches and longitudinal drainage facilities. Typically, the cross slope of the road surface in the transition section should be set between 1.5% and 2.5% to allow surface water to flow quickly into the shoulder and side ditch. Additionally, the selection of drainage facility materials should prioritize high-strength, corrosion-resistant, and water-permeable materials. For instance, permeable concrete blocks are recommended for drainage blind ditches, and polyethylene or polyvinyl chloride (PVC) pipes are preferred for drain pipes to prevent damage and corrosion over long-term use.

Finally, the arrangement of drainage facilities should be meticulously planned according to the actual terrain and hydrological conditions. Side ditches should be placed on both sides of the roadbed, with a width of 0.5 m to 1.0 m, and the depth can be increased according to the bridge's scale to enhance drainage capacity. During the design of drainage blind ditches, they should be placed at the bottom of the side ditches, and maintenance wells should be installed at the connections between the blind ditches and drainage pipes to facilitate later maintenance work [10].

5. Conclusion

In summary, this paper presents research on the structural design of roadbed pavement in the road and bridge transition section. After analyzing the importance of roadbed pavement structural design and exploring common

issues in the transition section, the research delves into four key areas: the design of lap plate and non-lap plate extradition sections, easing transition section design, abutment back design, and the design of road and bridge drainage systems. This comprehensive approach aims to form a well-rounded design system for roadbed pavement.

The progress of society is closely linked to the construction of road and bridge projects, and the quality of these projects has a significant impact on social and economic development. Therefore, road and bridge design and construction enterprises should draw lessons from this paper, strengthen research on roadbed pavement design in transition sections, and master scientific design approaches and technologies to ensure the overall quality of road and bridge projects.

Disclosure statement

The author declares no conflict of interest.

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