Analysis and Investigation on the Mechanical Properties of Bridge and Culvert Transition Section Overlap Plate

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Abstract. Bridge and culvert transition section is the key position of road and bridge connection, and its mechanical properties have a direct impact on traffic safety and road service life. In this paper, we focus on the bridge culvert transition section to set up the lap plate and not set up the lap plate under the two circumstances of the platform back jumping car force condition was analyzed. Subsequently, based on different construction situations, it discusses how to rationally use the length of the lap plate to achieve the goal of eliminating the bridge head jumping. At the end of the article, the key technology of backfill construction is proposed, which provides a scientific reference basis for the design and construction of bridge and culvert transition section.

Keywords: Bridge and culvert transition section; Mechanical analysis; Table back jump; Hitch plate

1 Introduction

Bridge and culvert transition section belongs to the weak zone of road and bridge connection, under the action of vehicle load, it is easy to appear uneven settlement, which triggers the phenomenon of bridge head jumping, which will have an impact on the safety and comfort of driving [1-2]. As an effective means of transition, the mechanical properties of the lap plate are directly related to the stability and durability of the transition section [3-4].

Generally speaking, the bridge head jumping phenomenon can be roughly divided into two categories [5]: one is the case of setting the bridge head plate. In this case, the back of the bridge will form a more moderate longitudinal slope, with the help of the transition function of the plate, the impact generated during the vehicle driving can be released smoothly, the bridge jumps significantly reduce the phenomenon. The second is the case of not setting up the bridge headboard. At this time, the bridge deck and the roadbed is very easy to appear between the obvious height difference, which is often referred to as the "step effect". Vehicles passing through will produce large bumps [6-7], which not only poses a threat to traffic safety, but also accelerate the damage speed of the roadway and abutment structure.

G. Zhao et al. (eds.), *Proceedings of the 2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTTCA 2025)*, Atlantis Highlights in Engineering 39,
https://doi.org/10.2991/978-94-6463-793-9_49

2 Analysis of the Force on the Jumping Car of the Platform Back at the Place of no Hitch Plate

As shown in Figure 1, in cement concrete and asphalt concrete road sections where bridge headers have not been installed, steep bumps or steps are formed at the bridge headers due to the settlement of the road base[8]. In terms of the actual driving conditions, the impact of such steps on driving, compared with the setting of the longitudinal slope of the roadway plate section of the impact of the turn is more prominent. Specifically, there are two main manifestations: first, it will make the driving speed reduced; second, it will make the driver and passengers produce a stronger sense of discomfort, and may even cause traffic accidents.

Firstly, in terms of forcibly reducing the driving speed. For example, on an urban road with a normal speed limit of 60 kilometers per hour, when a vehicle is driving normally to the longitudinal slope turning point of the section with an approach slab, due to the relatively gentle change in the longitudinal slope, the driver may only need to gently tap the brakes and reduce the speed to around 50 - 55 kilometers per hour to pass through smoothly. However, if encountering the step situation and driving at the same initial speed, in order to avoid excessive impact on the vehicle, the driver often needs to brake hard in advance to slow down. For instance, the driver may have to quickly reduce the speed to 30 kilometers per hour or even lower to slowly pass the step. This greatly affects the normal passing efficiency of vehicles and is likely to cause traffic congestion during periods of high traffic flow.

Secondly, regarding the significant increase in the discomfort of drivers and passengers and the potential threat to driving safety. For drivers, when the vehicle passes over the step, a strong sense of bumping will occur. This not only makes it difficult for the driver to maintain a good driving posture and precise control of the vehicle but also distracts their attention. For passengers, this discomfort is even more obvious. In severe cases, such as on a highway, the driver may be startled by suddenly encountering the step and make operational mistakes, which could lead to the vehicle getting out of control and then trigger serious driving safety accidents such as rear-end collisions and hitting the guardrail, causing huge losses to people's lives and property.

When there is a misalignment situation, the specific situation of the wheel force is shown in Figure 2.

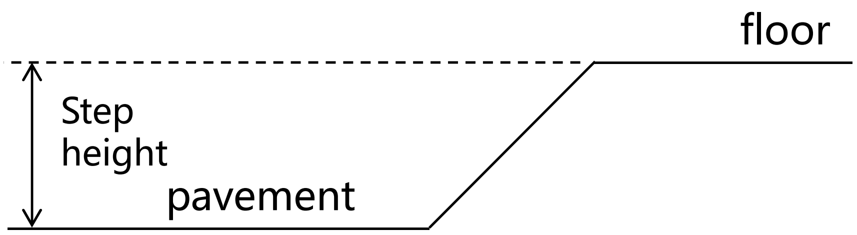

Fig. 1. Schematic of Settlement of Bridge Head without Lap Plate

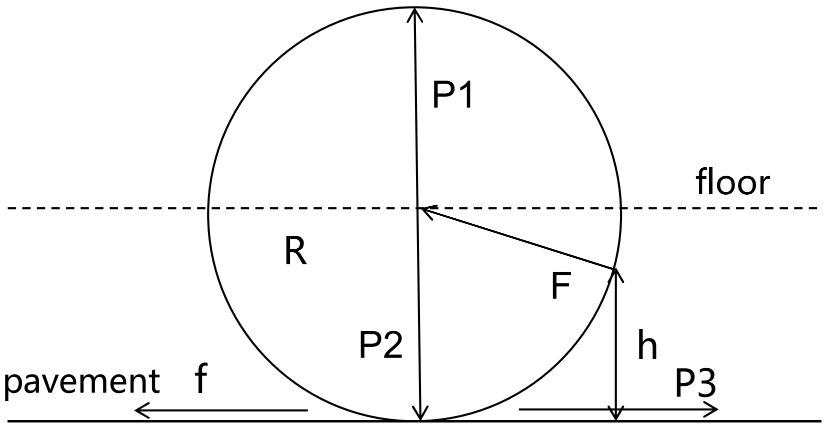

Fig. 2. Schematic diagram of a wheel without a hitch plate at the end of the bridge

Obtained from the mechanical relationship: conservation of force in the perpendicular direction:

$$P2\sqrt{R^2-h^2}+(P3-f)h=P1\sqrt{R^2-h^2} \tag{1}$$

Where: P1 - Impact force on the pavement; P2 - vehicle load;P3-horizontal force exerted on the pavement by the wheels, which is positively correlated with the vehicle load; h-Step height; f-friction; R-wheel radius.

P1 can be obtained:

$$P1=P2+\frac{(P3-f)h}{\sqrt{R^2-h^2}} \tag{2}$$

As shown in Equation 2, the impact force P1 borne on the road surface is closely related to the vehicle load and step height. Research shows [1]: in the Santana sedan, Dongfeng 140 trucks and other representative vehicles in the second level and above the highway bridge head step section of the field test found that, when the vehicle speed is maintained at 60 to 140 km / h, and step height does not exceed 1.5 cm, the vehicle driving almost unaffected; step height in the range of 1.5 to 5 centimeters, the vehicle will slow down the speed of travel, and with the When the step height is between 1.5 and 5 centimeters, the vehicle speed will slow down and be accompanied by more obvious bumps; once the step height exceeds 3.5 to 5.0 centimeters, the vehicle speed will decrease significantly and be accompanied by severe bumps; especially, when the step height exceeds 5.0 centimeters and the driving speed is higher than 80 kilometers/hour, the vehicle not only decelerates obviously, but also increases the bumps, and the driver also feels that it is difficult to manipulate the steering wheel, which constitutes a potential threat to the safety of the driving, which is a potential threat to the safety of driving on the bridges that are equipped with steps on both sides (This situation is particularly prominent on small bridges with steps at both ends (total length of 5 to 8 meters).

3 Bridge and Culvert Transition Section Set Up Lap Plate Platform Back Jumping Car Force Analysis

When the bridge deck is installed at the bridge head, the bridge abutment can be in a stable condition without settlement. However, as can be seen in Figure 3, if the embankment settles, the longitudinal slope of the line between the bridge abutment, the slab and the embankment will form a discontinuous bend. This discontinuous bend will cause the vehicle to suffer two bumps during travel.

This study focuses on the bend at the junction of the bridge deck and the embankment. Figure 4 presents a simplified model of a vehicle traveling on a road with a folded longitudinal slope, and Figure 5 shows the force characteristics of the front and rear axles of the vehicle .

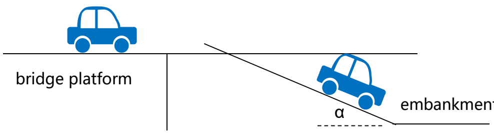

Fig. 3. Schematic diagram of jumping car when setting up the hitch plate

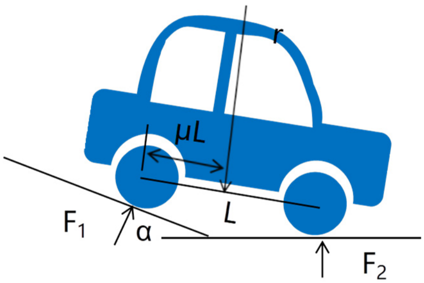

Fig. 4. Schematic diagram of the force on a vehicle passing through a curved section

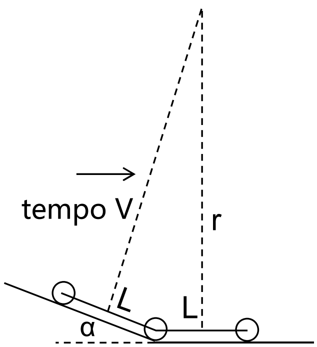

Fig. 5. Schematic diagram of front and rear wheel forces on the vehicle over the curved section

As shown in the above figure 5, the vehicle has a radius at the zigzag change in slope:

$$r = L/2/\tan\alpha = L/2i \tag{3}$$

Let the slope of the elevation angle α be i,In the actual site slope i is usually below 2%, so in the subsequent calculations, cosα=1 is taken.

When a vehicle travels from the bridge deck to the bridge head and passes over the overlap plate, we can regard this area as an approximately convex vertical curve section, given the relatively slight change in longitudinal slope in this area. When the vehicle travels in this section, it generates an acceleration on the vertical curve that points to the center of the curve, i.e., centripetal acceleration, which generates a centripetal force.

To alleviate the effect of centripetal force, the following measures can be taken: Optimize the design of the approach slab, reasonably set the length and gradient transition to make the vehicle transition more smoothly; Strengthen road maintenance to ensure the flatness of this area; Use traffic signs to remind drivers to slow down, reduce the vehicle speed, minimize the impact of centripetal force, and ensure driving safety and comfort.

The magnitude of this force can be calculated as:

$$F_2 = \frac{mV^2}{r} \tag{4}$$

The force on the rear wheels of the vehicle is:

$$F_1 = F_2(1-\mu) + mg(1-\mu) \tag{5}$$

Joint Eq. 4 and Eq. 5 can be obtained:

$$F_1 = m(V^2/r + g)(1-\mu) \tag{6}$$

From Eq. 6, it can be obtained that the rear axle bearing capacity is closely related to the turning radius, total weight, traveling speed and longitudinal gradient of the vehicle when it passes through the point of folding line and changing slope. In view of the bridge abutment and embankment in the stiffness of a significant difference, embankment in the settlement, even if the bridge set up lap plate, will form a certain longitudinal slope difference. Vehicles from the bridge to the embankment, the faster the speed, the heavier the load, the greater the longitudinal gradient, the vehicle to withstand the force is also stronger, resulting in a greater impact force, the value of which is usually several times the design load, which in turn causes the following chain reaction: settlement increase → impact force intensification → settlement further expansion, forming a negative cycle effect.

4 Study on the Suitability of Bridge Header Overlays

Scientifically selected bridge head lap plate can effectively alleviate the problems of localized subsidence and lateral slope change[9], which is essentially a supplementary measure aimed at compensating the effects of uneven settlement and trying to improve the unfavorable conditions caused by three sudden changes in slope, so as to eliminate the experience of jumping in the driving process. Obviously, in order to completely eradicate the phenomenon of bridgehead jumping, the core of designing the transition plate lies in reasonably determining its length.

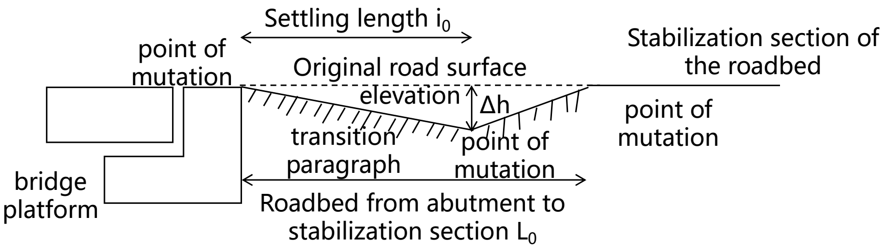

Fig. 6. Change in roadway longitudinal slope at bridgehead

As shown in Fig. 6, based on the length of the transition plate, it can be summarized as the following three cases:

(1) Hitch plate length L ≤ i0, if inconsistent settlement of bridge abutment and transition section roadbed occurs, the two ends of the transition plate will follow the sinking of the two, respectively, which will lead to the rotation of the bridge head transition plate on the axis of the simply supported end, so that the change of longitudinal gradient persists. As a result, the sudden change in longitudinal gradient remains significant for three times, i.e., the skipping phenomenon is not alleviated in any way, which is the least desirable condition[10].

(2)i0<lap length L<L0, the sudden change point will be shifted back from the maximum settlement point, thus alleviating the jumping vehicle phenomenon to a certain extent, but the three times of longitudinal gradient change is still not eliminated, and it fails to solve the jumping vehicle problem at the bridge head fundamentally.

(3) The length of the lap plate L>Lo, at this time, if you ensure that the end of the lap plate no longer occurs settlement or settlement is very small, then you can realize the elimination of longitudinal gradient mutation condition, thus eliminating the uneven settlement caused by jumping vehicle phenomenon.

5 Key Technology of Backfill Construction

(1) Site Preparation and Substrate Improvement: ①Cleaning: When the concrete strength of the bridge abutment reaches the standard, clean the construction area comprehensively, remove sundries and crop residues, and ensure that the storage area is neat and solid. ② Mapping and positioning: according to the design drawings, accurate

positioning, using a total station to clarify the boundaries and elevation differences, laying the foundation for subsequent work. ③ Backfill planning: determine the limits of backfill, select the lowest point for the bottom from the surface and the top of the bearing platform after clearing the table, widen to the upper part of not less than 3 meters, according to a specific slope decreasing, forming an inverted trapezoidal shape, to ensure that the abutment structure is stable and supportive. ④ Foundation reinforcement: in accordance with the specifications, first clean up the substrate impurities, to ensure that there is no stagnant water, pollution, and the back of the platform synchronized with the selection of suitable material backfill, layer by layer (≤ 15cm), tightly compacted to the specified density.

(2) Construction techniques and quality control: ①Step construction: set up multistage ladder-like structure, width and height to suit different lots, 4% inward inclination, facing the side of the roadbed material is 15° slope, step by step excavation, immediate filling, to maintain a solid structure. ② Material selection: preferably gravel soil, large particles >50%, fines <10%, if weathered rock is selected, hardness ≥30MPa and resistance to water erosion, giving priority to the remaining gravel in the excavation section. ③ Process implementation: mark the layered compaction line, loose layer ≤ 20cm, compacted layer ≤ 15cm, manual fine trimming edges, consistent with the bridge flow. Check the image record between layers and continue the next step through quality inspection.

(3) implementation points: ① accurate measurement of filler volume, with the help of machinery supplemented by manpower leveling, special areas of light equipment to strengthen, strict control of the degree of compactness, away from the main facilities using small tools to maintain structural integrity. ② In the backfill operation, the relevant concrete components must reach the specified strength; the two platforms should be filled at the same time symmetrically, especially to prevent the formation of unilateral pressure on the structure. (iii) The backfill construction of the bridge abutment and cone slope should be carried out synchronously, and ensure that the design width can be reached after compaction and renovation. The backfill part of the roadbed should be synchronized with the embankment bed. ④ Culvert, channel and other single-span structures, backfill on both sides should be carried out after the installation or pouring of cover plate, eight-wall, one-wall and support beams are completed, and backfill and compaction should be carried out symmetrically on both sides of the cave in layers.

6 Conclusion

In this paper, the mechanical properties of bridge-culvert transition section overlap plate and its influence on the phenomenon of platform back jumping vehicle are discussed in depth. It is pointed out that the setting or not of overlap plate significantly affects the smoothness of vehicle traveling and the durability of road structure. By comparing and analyzing the force characteristics of the platform jumping under the case of setting up a lap plate and without a lap plate, the key role of the lap plate in mitigating the jumping problem at the bridge head is revealed. It is found that the reasonable design of the length of the plate is the key to eliminate the jumping phenomenon, and the length of the plate should be larger than the critical length to avoid the sudden change of the longitudinal slope, so as to ensure the safety and comfort of driving.

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