Research on Emergency Repair Technology of Overhanging Pavement Slabs on Defected Subgrade Caused by Flood

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Abstract. Overhanging pavement slabs on the defected subgrade are mainly caused by flood erosion that partially hollows out the subgrade, which leaves the highway in an unstable condition. This paper develops a kind of emergency repair technology of suspended road slab anchor pulling technology for this type of disaster, combining the working principle of self-anchored emergency anchors with its components, calculating the road slab through the equivalent method of concrete road slab combined with structural mechanics, analyzing the stability of this emergency repair technology, proving that this kind of emergency repair technology can be applied in the actual situation of the emergency, enriching China's repair methods of water damage to the roadbed, and meeting the strategic needs of the transportation construction.

Keywords: subgrade defects, seepage, emergency repair, theoretical calculation.

1 Introduction

Highway flood damage, noted as one of the most significant causes of highway subgrade defects, became a concern of the Highway Department in the 1960s. The research on highway flood damage initially focused on the research on scouring of highway structures-bridges, and achieved a number of scientific research results, such as scouring calculation of bridge abutments, aperture calculation of large and medium-sized bridges, and design flow calculation of large and medium-sized bridges. More research on flood damage mechanism, calculation methods and protective measures of highway water damage around the 21st century, several scholars studied highway flood damage from the perspectives of eradicating highway flood damage [1], flood resistance [2], etc.; Shen Bo and other highway small bridge and culvert, drainage and energy dissipation facilities, carried out a flood damage investigation [3], scouring test [4] and flood damage prevention and control [5] research; Li Xiaoming on water damage repair technology for road along the river research [6]; Wu Shuwei conducted a study on rapid repair of roadbed collapse disaster [7]; Sun Jin and Tian Weiping equal to the river along the roadbed

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and protection structure scour water damage problems, using model test [8-10] and numerical simulation methods [11] to explore the optimal design parameters of the protection project; 1960s the United States of America highway large-scale rise, in order to adapt to the engineering and construction of a large number of bridge abutments Scour, bridge water damage and water damage roadbed protection and other aspects of the research. In the emergency access to the road, the initial assembly of highway steel bridge (known as Bailey Bridge abroad) by the British Donald Bailey (Sir Donald Bailey) engineers designed in 1938, available for a variety of vehicles through rivers, ditches and other obstacles, and can be used in the dangerous bridges, broken bridges erected on the bridge and in the emergency use of the road repair by the prefabricated metal components, after several decades of practice proved that the temporary steel bridge is fast, economic, reliable, but there are some problems.

In addition, many scholars have conducted other unique studies on highway water damage, and Hairui Li et al. analyzed the advantages and practices of biological control of bridge water damage to improve the ecology, enabling the bridge construction to be in harmony with the natural environment [12]. Wu Yong et al. introduced the application of ground-penetrating radar in the detection of highway water damage [13]; Qin Jun et al. conducted a hazard evaluation of slope water damage on the Zhouzhi section of National Highway 108 and carried out an investigation of slope water damage disaster on the Zhouzhi section of National Highway 108 [14]; Zhao Han proposed the use of pouring foam concrete as a rapid repair program for water-damaged roadbeds [15]; and Wang Xing and Gao Jianjun conducted a study on water damage repair technology for subgrade [16-17]. Jain A K, Jha A K and Shivanshi conducted a comparative study, which explored how to improve the performance of subgrade soil[18]. Kishor R, Singh V P and Srivastava R K used rice husk ash to mitigate the expansive soil of highway soil[19]. Ashpiz E S and Zamukhovskiy A V proposed a method to strength the subgrade used for heavy cars[20]. Ghani A N A, Roslan N I and Hamid A H A studied road submergence during flooding and they explained its effect on subgrade strength[21].

2 RESEARCH CONTENT

Highway roadbed deficiency disasters are socially sensitive. Ensuring the availability of people's transportation and the safety of life and property is a priority in the aftermath of the disaster. Under the research and efforts of all parties, the technologies in place for disaster prevention and control have become relatively abundant. Under the topographic conditions of the plain and hilly areas, the highways are mostly in high-fill mode, and the subgrade on both sides of the road is easily destroyed under the impacts of floods and heavy rains. In order to quickly restore traffic and meet the needs of emergency disaster management, it is necessary to develop new emergency road repair methods to quickly repair the water-damaged sections and shorten the construction time in a race against time. Compared with the conventional repair technology of water damage missing section, emergency repair has rapidity. The water-submerged erosion effect of heavy rains and floods makes the subgrade eroded to the extent of causing overhanging pavement slabs on defected subgrade, which causes serious safety hazards to normal traffic, especially to people in emergency shelter.

The bearing capacity of the reinforced concrete pavement of this technology is 50kN per linear meter, which allows to withstand the access of vehicles and pedestrians not exceeding flat semi-trailers. The technology can be in the reinforced concrete highway in the pavement slab still remains, and the lower part of the subgrade defect width is less than one-half of the width of the subgrade, can be in the reinforced concrete pavement lower part of the subgrade defect 5 ~ 8 hours after the installation is completed, to achieve the emergency repair of the highway and to guarantee the access,as shown in Figure1~Figure3.

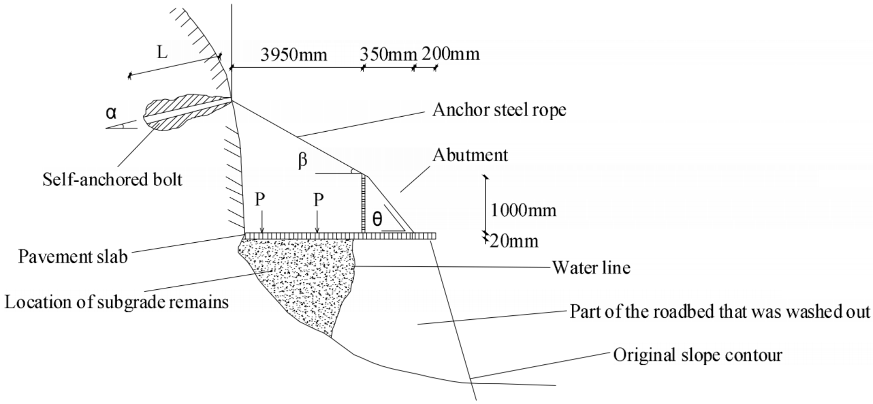

Fig. 1. Section structure diagram of suspended pavement slab

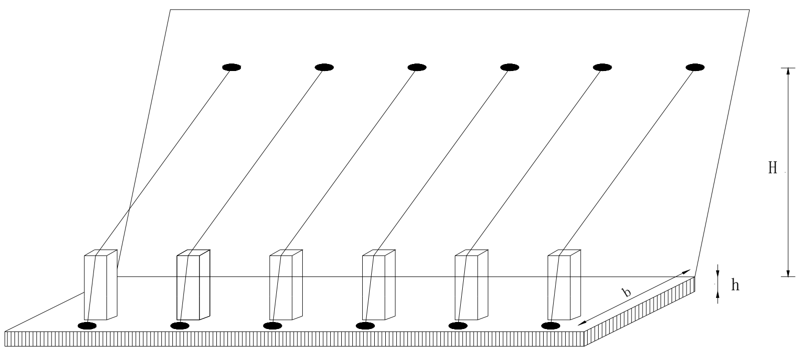

Fig. 2. Facade of overhanging subgrade pavement slab repair

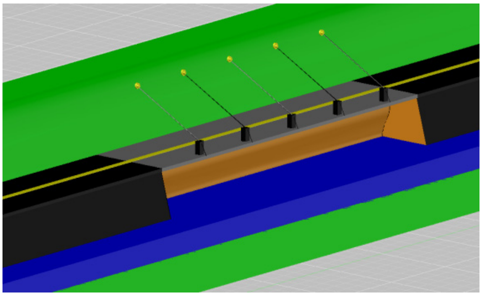

Fig. 3. Three-dimensional diagram of pavement slab repair of hanging subgrade

3 Internal force calculation of suspended pavement slab.

In comparison with the thickness and width of the pavement slab, the length of the pavement slab is still relatively long, hence the pavement slab can be regarded as an infinite width pavement slab. The tension of the anchoring steel ropes is uniformly distributed on the outer side of the pavement slab. Car load in the overhanging pavement slab is different from the rope on the pavement slab tension is also different. When the center of gravity of the wheel and the steel rope in the same cross-section, the corresponding steel rope for the concrete road panel tension is the largest, it is assumed that the outer side of the wheel load completely in the nearest steel rope. According to the General Specification for Highway Bridges and Culverts JTGD60-2015, the automobile traveling on the suspended road panel is a permanent action, and the action of the concrete pier is also regarded as a permanent action,as shown in Figure 4~Figure 6,the calculation formula is as follows:

$$G_k = \gamma V \tag{1}$$

Formula:

G_k —Structural gravity standard value, kN;

γ —Material weight, kN/m^3;

V —Volume m^3.

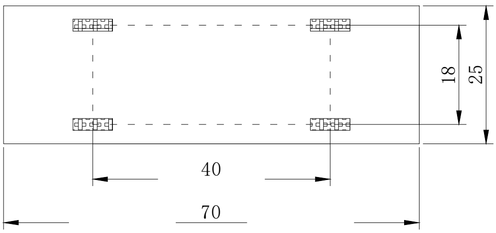

Fig. 4. Plane layout of car wheels on the road plate Method

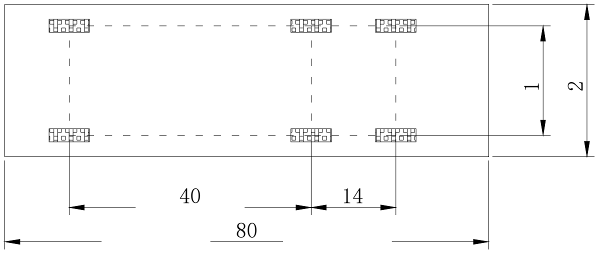

Fig. 5. Plane layout of car wheels on the road plate Method 2

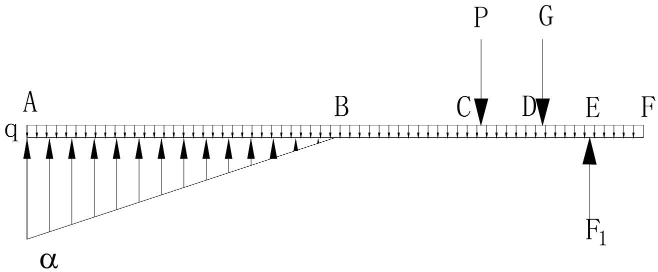

Fig. 6. Basic schematic diagram of force on pavement slab

When the center of gravity of the wheel and the newly born are in the same section, the force analysis is carried out, the elastic modulus *E* of the flash position of the reinforced concrete pavement slab and the moment of inertia I_Z take the same value, the remaining subgrade is regarded as consolidated under the pavement slab, the uniform weight of the reinforced concrete pavement slab is regarded as uniform distributed load q, and the lateral tension of the anchoring steel rope is decomposed into horizontal and vertical forces, and the vertical force is F_1. The remaining roadbed is *bx*, *P* is the vehicle load, *G* is the gravity of the steel rope support pier, and *l* is the distance between the wheel and the inner edge. According to the force diagram, it can be seen that:

The calculation formula is as follows:

$$\frac{F_1}{\sin\theta}\cos(\theta-\beta)=F \tag{2}$$

$$\theta = acr\tan\frac{l_1}{b_1} \tag{3}$$

$$\beta = acr\tan\frac{H-l_1}{b_0} \tag{4}$$

According to formula:

$$G = a_1 \times a_1 \times l_1 \times \rho \times g \tag{5}$$

The structure in this paper belongs to the statically determinate structure and its equilibrium equation can be written as

$$\frac{1}{2}\alpha(b - b_x) + F_1 = P + G + qb \tag{6}$$

Then the undamaged part of the foundation can be determined

$$\alpha = \frac{2(P + G + qb - F_1)}{b - b_x} \tag{7}$$

Take the moment at the inside point A

$$\frac{1}{2}(b - b_x)\alpha\frac{1}{3}(b - b_x) - \frac{1}{2}qbb - Pl - G(b - b_2 - b_1) + \mathrm{F}_1(b - b_2) = 0 \tag{8}$$

$$\begin{aligned}\mathrm{F}_1 &= \frac{\frac{1}{3}(b - b_x)(P + G + qb) - \frac{1}{2}qb^2 - pl - Gb_0}{\frac{1}{3}(b - bx) - b + b_2} \\ &= \frac{\frac{1}{3}(b - b_x)(P + G + qb) - \frac{1}{2}qb^2 - pl - Gb_0}{b_2 - \frac{2}{3}b - \frac{1}{3}b_x}\end{aligned} \tag{9}$$

After taking the moment, the internal force of each point can be obtained respectively.

$$M_B = \frac{1}{3}\alpha(b - b_x)^2 + P(l - b + b_x) + G(\mathrm{b} - b_1 - b_2) - F_1(b - b_2) - bq(\frac{b}{2} - b_x) \tag{10}$$

$$M_c = \frac{1}{2}\alpha(b - b_{\mathrm{x}})(l - \frac{1}{3}b + \frac{1}{3}b_{\mathrm{x}}) + G(b - b_1 - b_2 - l) - \mathrm{F}_1(b - l - b_2) - bq(\frac{b}{2} - b_2) \tag{11}$$

$$M_D = \frac{1}{2}\alpha(\mathrm{b} - \mathrm{b_x})(b - b_1 - b_2) - P(b - l - b_1 - b_2) - F_1 b_1 - qb(\frac{b}{2} - b_1 - b_2) \tag{12}$$

$$M_E = \frac{1}{2}\alpha(b - b_{\mathrm{x}})(b - b_2) - P(b - l - b_2) - Gb_1 - qb(\frac{b}{2} - b_2) \tag{13}$$

One section of the anchoring steel rope is connected with the self-anchoring emergency bolt on the cliff wall, and the other end is locked on the outer side of the suspended reinforced concrete pavement slab structure. The anchoring steel rope is a steel strand determined by the scene, and the longer the steel rope is, the greater the tension will be, and the above formula can be obtained,the calculation formula is as follows:

$$F = \frac{F_1}{\sin\theta}\cos(\theta-\beta) \tag{14}$$

The closer the wheel is to the outer end of the suspended road plate, the greater its tension. In the structural calculation, if a certain size of the steel strand is selected, the tension received by the steel rope should be less than the maximum allowable design bearing capacity of the steel rope,the calculation formula is as follows.

$$F = \cos(\theta-\beta)\frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{\sin\theta(b_2-\frac{2}{3}b-\frac{1}{3}b_x)} \tag{15}$$

When selecting a certain size of steel strand in structural design, the pressure on the steel rope should be less than the maximum allowable bearing capacity of the steel rope, and the number of steel strands required can be calculated, the calculation formula is as follows:

$$F \le \frac{nAsf_{sd}}{\eta} \tag{16}$$

$$n \ge \left[\frac{\cos(\theta-\beta)\eta}{Asf_{sd}}\frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{\sin\theta(b_2-\frac{2}{3}b-\frac{1}{3}b_x)}\right] \tag{17}$$

Formula:

f_{pd}—Stress strength of single strand, MPa;

n—The number of strands;

A_S—Area of a single strand, m^2;

η—steel rope safety factor;

[]—The calculation result is an integer;

4 Engineering Examples

4.1 Project Overview Specimens results

Youxi County, Fuzhou City, Fujian Province, is a frequent section of roadbed missing. In the rainstorm season, the road roadbed is seriously damaged by water, and the outer side of the roadbed is hollow. The water rises quickly, and the water is immersed into the roadbed, resulting in the partial foundation of the roadbed being hollow, and the single-lane lane with a width of 4.5m is formed over 10m with a suspended section of 2m. When the flood is not suitable for traditional repair methods, emergency repair techniques are used to reinforce it so that pedestrians and small vehicles can easily pass through it. According to the provisions of China's urban and road general specifications, the maximum load of the upper vehicle is 100kN, the car load is 75 kN in accordance with China's general specifications, the front axle: rear axle is 1:3 standard axle load, the thickness of the concrete road slab is 0.20m, the structural weight q is 3kN/m, and the pedestrian load is omitted in the calculation. The reinforcement and repair dimensions are h=0.20m, b2= 0.20m, b1= 0.15m, b0= 3.95m, bx= 2.50m, the cross-sectional area of the steel rope support pier is a1×a1=0.20m×0.20m, and the height of the steel rope support pier is l1=1.00m. The reinforcement and prefabrication were constructed according to the ordinary reinforced concrete structure, in which the concrete was C30 and the anchor steel rope was 15.2mm steel strand. The internal friction Angle between the anchor blade and the drilled side wall was 25.5° during the repair process. The cohesive force between the anchor blade and the borehole side wall is 147kPa. As shown in Figure 7.

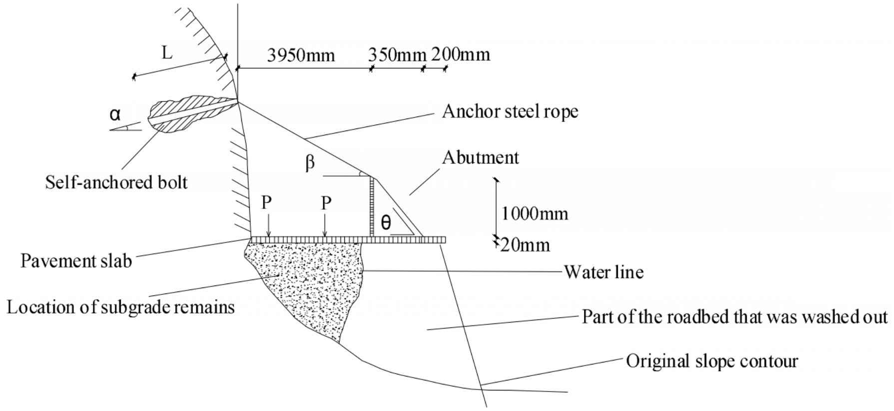

Fig. 7. Schematic diagram of anchoring technology of suspended pavement slab

4.2 Structural calculation

According to the geometric relationship in the figure above, b_0= 3.95m, b_1= 0.15m, b_2= 0.2m in the pavement slab;According to the proportion relationship, H=3.50m, the un-suspended part b_x= 2.5m, 15.2mm steel strand As=1.65×10^{-4}m^2,f_{pd}=1.26×106 kPa, and l is 2.15m according to the vehicle layout on the road. By using the dimensions in the above formula, the data can be substituted into the above formulas, and the following results can be obtained:

$$\theta = acr\tan\frac{l_1}{b_1} = 81.5° \tag{18}$$

$$\beta = acr\tan\frac{H-l_1}{b_0} = 32.3° \tag{19}$$

$$G = a_1 \times a_1 \times l_1 \times \rho \times g = 10kN \tag{20}$$

$$\begin{aligned} F_1 &= \frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{\frac{1}{3}(b-bx)-b+b_2} \\ &= \frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{b_2-\frac{2}{3}b-\frac{1}{3}b_x} \\ &= 47.85kN \end{aligned} \tag{21}$$

$$\alpha = \frac{2(P+G+qb-F_1)}{b-b_x} = 50.65kN \tag{22}$$

$$\begin{aligned} n &\geq \left[\frac{\cos(\theta-\beta)\eta}{Asf_{sd}}\frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{\sin\theta(b_2-\frac{2}{3}b-\frac{1}{3}b_x)}\right] \\ &= \left[\frac{\cos(81.5°-32.3°)\times 2.5}{Asf_{sd}}\frac{\frac{1}{3}(4.5-2.5)(75+10+3\times 4.5)-\frac{1}{2}\times 3\times 4.5^2-3\times 2.15-10\times 3.95}{\sin 81.5°(0.2-\frac{2}{3}\times 4.5-\frac{1}{3}\times 2.5)}\right] \\ &= 0.38 \end{aligned} \tag{23}$$

$$F = \cos(\theta-\beta)\frac{\frac{1}{3}(b-b_x)(P+G+qb)-\frac{1}{2}qb^2-pl-Gb_0}{\sin\theta(b_2-\frac{2}{3}b-\frac{1}{3}b_x)} = 31.61kN \tag{24}$$

n is taken to be 1, then when the pavement is suspended by 2m and the number of steel strands at the pier column is 1, the structure is stable and the number of emergency anchor rods is 1. The anchoring depth calculation using 80kN specification bolt can meet its requirements.

Self-anchoring anchors of size 80kN were used, with an internal friction angle of 25.5° between the anchoring blade and the sidewall of the borehole. *c* is the cohesion force between the anchoring blade and the side wall of the drilling hole, and its magnitude is 147kPa; n is the number of anchoring sections, which is 6; r is the original length of the support piece; r' is to shorten the length of the support sheet; m is the diameter of the drilling hole, its size is 0.085m; E is the elastic modulus and its magnitude is 210GPa; A is the cross-sectional area, and its specification is 0.04m×0.005m; S is the contact area between the anchoring blade and the drilling side wall, its specification is 0.04m×0.45m, h' is the contact length between the anchoring blade and the drilling side wall is 0.04m, its design bearing capacity is 80kN, substituting the data, can be derived:

$$P = [P] = 80kN$$
$$P = \frac{2n(r - r')EAm}{rr'}\tan\varphi + 4nb'h'c \tag{25}$$

$$r' = \frac{r}{1 + r\dfrac{P - 4nb'h'c}{2nEAm\tan\varphi}} \tag{26}$$

After bringing in the data and simplifying it, we can get:

$$r' = \frac{r}{1 + 0.00348r} \tag{27}$$

$$r = \sqrt{\left(\frac{l_0}{2n}\right)^2 + \left(\frac{m}{2}\right)^2} = 0.332 \tag{28}$$

The calculation formula is available

$$r' = 0.329 \tag{29}$$

$$r' = \sqrt{\left(\frac{3.3 - \Delta l}{10}\right)^2 + \left(\frac{0.085}{2}\right)^2} \tag{30}$$

$$\Delta l = 0.0286 \tag{31}$$

It can be seen that when the precession is about 0.0286m, the required requirements can be reached and used together.

Follow the steps below:

(1) At the place where the edge of the suspended pavement slab is inside the edge of the free surface of the suspended concrete pavement slab (b_1+b_2), the steel rope support pier is positioned along the road extension direction according to the spacing a. 20cm is taken for b_1, 15cm for b_2, and 150cm for a. Wind gun is used to drill holes, and the precast reinforced concrete steel rope support pier is placed in the corresponding position.

(2) At the part of the surface height H of the inner slope of the highway and corresponding to the steel rope pier, the wind gun is used to drill holes, and the preset self-anchored bolt is placed in the hole, and the anchor head is tightened to make the bolt under load.

(3) Mechanically connect one end of the anchoring steel rope to the top of the self-anchoring type anchor rod, and the other end through the steel rope support pier. The fixed position on the pavement slab is selected at b_1 outside the steel rope support pier. By drilling holes in the concrete pavement slab, the steel rope end is plugged in, and the locking device is used at the bottom of the concrete pavement slab to lock and tighten the locking device. Cut the excess rope and repeat until reinforcement is installed throughout the road.

5 Calculation

(1) Overhanging pavement slabs on defected subgrade are mainly caused by flood erosion that partially hollows out the subgrade, which leaves the highway in an unstable condition. This paper develops a kind of emergency repair technology of suspended road slab anchor pulling technology for this type of disaster.

(2) Through the concrete road panel equivalent method combined with structural mechanics, calculations were carried out to analyze the stability of this emergency repair technology. Specific calculation formulas and specific construction methods were derived, proving that this emergency repair technology can be applied in actual disaster situations.

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