Analysis of the mechanism of roadbed failures caused by water and roadbed drainage system design

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Abstract: Analysis of the failure of different types of roadbed caused by water in mountainous areas, shows a key factor to be seepage of rainfall into the unsteady slope, causing groundwater in the landslide to seep into the roadbed. This causes deformation of both the landslide and the roadbed. A drainage system located in the sliding slope is should be installed at the time of highway construction in mountainous areas, and this can lower the groundwater level and inhibit roadbed failure. Using an example from Chongqing, China as an example, the proposed system is tested and lowering of the groundwater level is observed. It is recommended that road all road construction includes such a drainage system in mountainous areas in the future.

Résumé: Le problème de la fondation qui est détruit par l'évacuation difficile de l'eau souterraine de la fondation interne et l'infiltration de pluie de la pente de la fondation est prise en considération importante dans la construction de la route moderne. Le texte a fait l'analyse de mécanisme de la destruction de la fondation de la route de montagne des différents types de la catastrophe de destruction de la pluie. On a proposé la variation des champs de transfusion à l'interne de la pente instabilisée causée par l'inflltration de la pluie. Cette variation a fait l'inféroflux coulant latéralement vers la fondation est le facteur plus clef et plus animé de catastrophe de la fondation. Et on a proposé l'arrangement de l'assainissement de la pente au cours de la conception de l'assainissement de la fondation. Il peut empêcher effectivement la naissance de la catastrophe de la fondation détruite par l'eau souterraine. La thèse a éprouvée par les résultats de la simulation numérique tri-dimensionnelle de la conception de l'assainissement de l'autoroute quelconque de Chongqing,China. La proposition de cette conception a un sens indiqué pour la construction de la route dans la montagne à l'avenir.

Keywords: roadbed failure, mountainous area, seepage, deformation, roadbed drainage system, 3-D models

PREFACE

Recent economic development in the mountainous areas of south-west China, has been accompanied by a sharp increase in transport and traffic. Improved highway quality requires roadbed drainage systems to be properly designed. Attention has focussed on groundwater in roadbeds, causing deformation and fracture.

Research into highway roadbed failure in mountainous areas shows that rain water seeping into unsteady ground causes landslides, and as the groundwater field changes groundwater flows into the roadbed to compound the deformation of the landslide and failure of the roadbed. Slope stability coefficients of the saturated rock and soil are generally between only 0.5 and 0.8. A properly designed drainage system can effectively lower the groundwater level, and prevent water damage to the roadbed. This paper describes a 3-D numerical model of a groundwater seeping field in Chongqing, China, and a design that is recommended for highway construction in mountainous areas.

FUNCTION OF GROUNDWATER TO THE SIDE SLOPE AND ROADBED

Slope stability is unavoidably affected by highway construction, and landslides are a constant problem. Different degrees of failure result from different types of seepage in different geological environments. Groundwater is more destructive than surface water to the side slopes and roadbed. Half-excavated and half-filled roadbeds with instable slopes are the most vulnerable.

Breakage function of groundwater to the side slope

The destructive functions of groundwater in rock and soil caused by increasing water pressure divide into three aspects: (1) it lowers the positive stress and the resistance on the sliding surface; (2) it increases the weight of the rock and soil; (3) it causes fractures to expand and fail.

Destructive function of groundwater to the roadbed

(1) The filled roadbed

Filled roadbed is always placed in low-lying or damp places such as marshes. Groundwater ingresses the roadbed from adjacent slopes to form different water levels on either side of the roadbed. This accelerates the water flow across the roadbed and washes the finer sand and soil away. Less permeable material can be used to block the flow (such as soft soil layer), protecting the roadbed from failing and sinking (Figure 1).

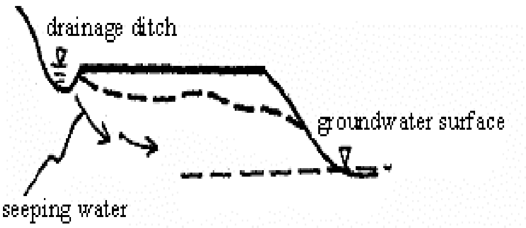
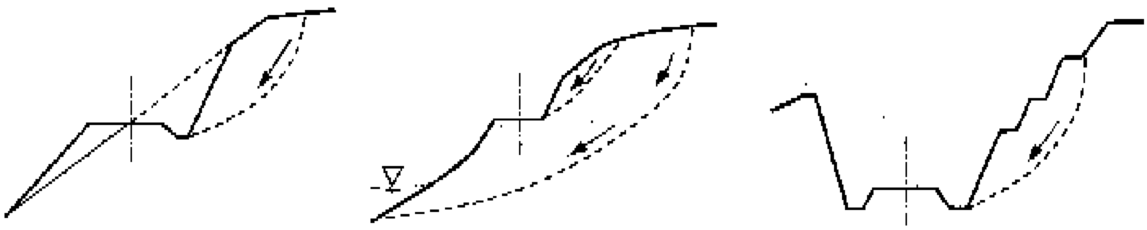


Figure 1. Deformation mode of roadbed under destructive lateral seepage

(2) The excavated roadbed

The destruction of an excavated roadbed caused by water is similar to the filled roadbed, but weakly permeable material inhibits cross-flow in the roadbed. The roadbed is saturated causing the water level to rise and the drainage system to be flooded. In this situation, the dug roadbed deforms gradually, sinks and fails with syrup type breakage (Figure 2).



(a) (b) (c)

Figure 2. The deformation mode of excavated roadbed caused by seepage of sliding slope

(3) The half-excavated and half-filled roadbed with a sliding slope

Groundwater in the sliding slope can: (1) cause seepage from the rock and soil in the sliding slope to flow into the roadbed and carry fine sand and soil grains from the filled-roadbed as in Figure 1. If the roadbed prevents groundwater from leaking out or it contains weakly permeable layers, the groundwater ingress can make the water-saturated material expand, and lead to deformation and destruction. As a result, the road surface is damaged or split and the roadbed is sand boiled; (2) during rain, groundwater flows into the incompact filled soil or along the boundary layer of the half-excavated and half-filled roadbed, and it can cause the rock and soil to separate. If there is no support at the foot of the filled-roadbed, the roadbed will slide away (Figure 3).

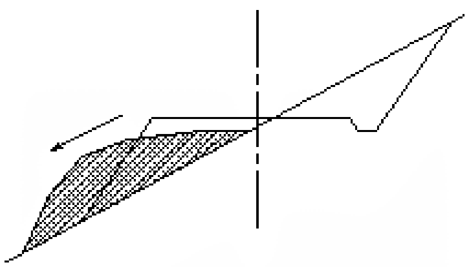


Figure 3. The slippage of dug and filled roadbed by the action of deadweight and water

In view of the important role groundwater has in highway destruction it is critical that drainage systems are built in at the construction phase.

Drainage systems may comprise a variety of different structures. The key to long-term safety and reliability of the system is to make it efficient and cost effective.

EXAMPLE OF ROADBED DRAINAGE SYSTEM DESIGN

A half-excavated and half-filled roadbed in Chongqing, China crosses the edge of a former landslide, and rain causes separation fractures in the incompact soil on the body. Separation fractures supply water into the landslide and roadbed, and the stability of the landslide and roadbed is compromised. The destructive function of groundwater in the sliding slope requires the drainage system in the landslide to be designed simultaneously with the roadbed. The groundwater flow field and the effect of the whole drainage system can be simulated using a 3-D numerical model.

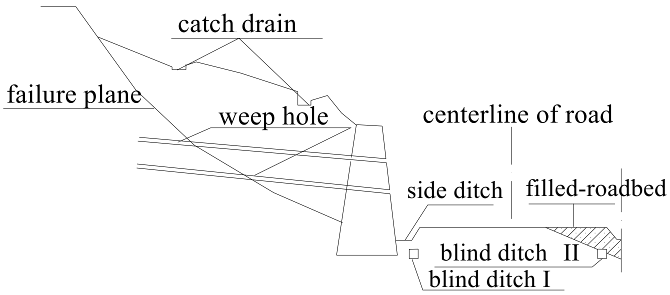


Figure 4. Schematic figure of drainage system design of the highway in Chongqing, China

Design of the drainage system

The drainage system design is strengthened as in Figure 4. The functions of the main structures are:

(1) The side ditch is situated between the roadbed and the landslide. It can drain groundwater from the landslip area away as surface water. Its size should be appropriate for the likely volume of seepage.

(2) The longitudinal blind drain is designed to intercept groundwater from the landslip, to eliminate seepage inside the roadbed and to lower the groundwater level. The longitudinal blind drain must not flood. An inverted filter is placed at the up-gradient side and a water-resisting layer is put to the other side. This can prevent fine sand and soil grains carried by the flow from blocking the blind drain. The dimension of the blind drain must also be appropriate for anticipated flow volumes.

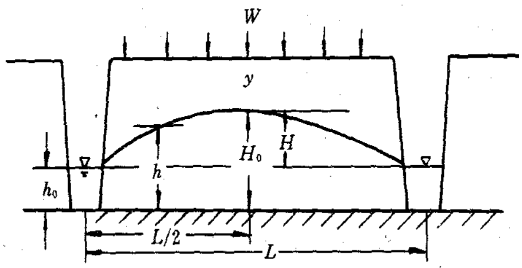


Figure 5. The calculation model of seeping channels

The model used to calculate the interval between the longitudinal blind drains is shown in Figure 5. The bearing stratum is 3m. Under conditions of continuous rainfall seepage occurs from the road surface, and if the seepage equals the groundwater transport, the state of groundwater flow is steady, and the groundwater transport can be described as:

$$K\frac{d}{dx}\left(h\frac{dh}{dx}\right) + W = 0 \tag{1}$$

as $h_m = \frac{1}{2}(H_0 + h_0)$ the equation can be simplified as:

$$\frac{d^2h}{dx^2} = -\frac{W}{Kh_m}$$

under the border condition of:

$$h\big|_{x=0} = h_0,\ h\big|_{x=L} = h_0$$

then the equation becomes:

$$h^2 = h_0^2 + \frac{W}{K}(Lx - x^2)$$

When water level in the middle of roadbed ($x = L/2$) is highest as:

$$H_0:\ h^2{}_{\max} = H_0^2 = h_0^2 + \frac{WL^2}{4K}$$

The interval between the two longitudinal under drains is given by:

$$L = 2\sqrt{\frac{K}{W}(h_{\max}^2 - h_0^2)}$$

and the amount of groundwater discharged by the under drain is:

$$q = WL$$

When the rain stops (w=0), the original water level in the under drain is H_0 and the water level in the middle of roadbed drops from h_0 to h_1, and the movement of groundwater can be described as:

$$\left.\begin{array}{ll} K\dfrac{\partial}{\partial x}(h\dfrac{\partial h}{\partial x}) = \mu\dfrac{\partial h}{\partial t} & (0 < x < L, t > 0) \\ h(x,0) = H_0 & (0 < x < L) \\ h(0,t) = h_0 & (t > 0) \\ h(L,t) = h_0 & (t > 0) \end{array}\right\}$$

For $h_m = \frac{1}{2}(H_0 + h_0)$, the interval of the two longitudinal under drains is given by:

$$L = \pi\sqrt{\frac{Kh_m t}{\mu \ln\dfrac{4H}{(h_1 - h_0)}}}$$

Symbols in the expression are that:

H --- difference of water level, $H=H_0-h_0$, m;
h_1 --- water level in the middle of roadbed at time of t, m;
μ --- specific yield of the aquifer;
t --- time of drainage, d

Other parameters used in the calculation are list in Table 1.

Table 1. Parameters used for interval calculation between the two blind channels

Parameter	Permeability coefficient K(m/d)	Intensity of rainfall w(mm/d)	Width D_0(m)	Specific yield	Length of roadbed L_0(m)	Influent coefficient (m/d)	Initial water level H_0(m)
Body of landslide	0.032~0.08	8	24.5	0.08	125	0.02	4.5
Bedrock	0.5						
Filled soil	0.0323						

The calculation indicates that the design interval between the two longitudinal blind drains should be about 8m, and the depth 5m. The relationship between falling velocity of water inside the blind drains and time (Figure 6), shows that the water level reduces to an acceptable level about 16 days later.

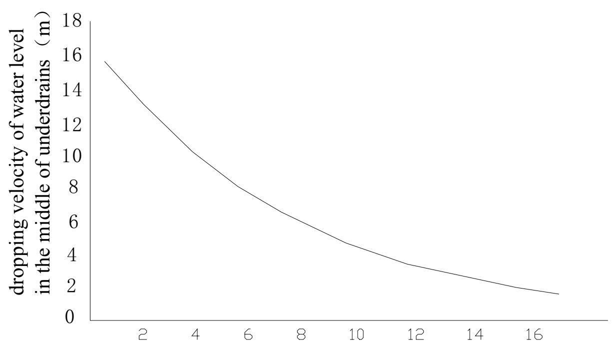


Figure 6. Drop of the groundwater level inside of two blind channels with different draining time

(3) Lateral blind drains are put at the two borders of the landslip and the roadbed to intercept groundwater in the roadbed. A weakly permeable layer should also be placed against the higher water level.

(4) Catch drainsare placed along the contour line to intercept surface water from the landslide flowing towards the roadbed.

(5) Drainage pipes are often designed to discharge groundwater inside the landslip. They can effectively reduce hydraulic pressure in the landslip and prevent groundwater flowing into the roadbed. The effect of the drainage pipes is determined by: angular altitude, depth and space, the location of the hole.

For the drain to lower the groundwater level, the angle should be between 10% and 15%.

The depth of the drains should be should reflect the groundwater level inside the landslip. The height of the inclined drainage pipes should be in accord with the groundwater table, the depth can be calculated by:

$$L = \frac{H - h}{\sin \alpha}$$

where:

H is the lowest high of groundwater table

h is the high of drainage inclined hole

α is landslide angle of drainage-hole

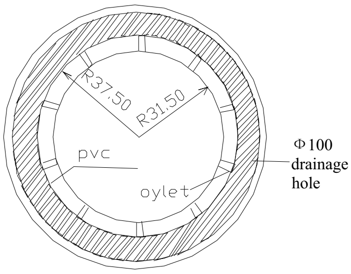
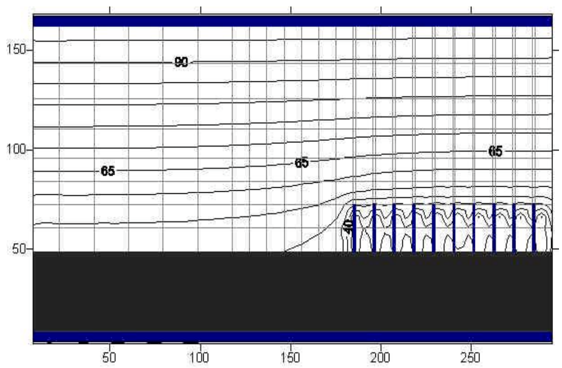


Figure 7. The filter composition of the draining pipes

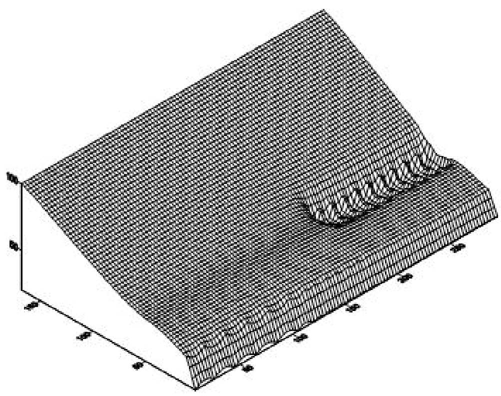
A filter should be included inside the drainage pipes (Figure 7). The diameter is 100mm in this design. Other parameters are defined in the Code of Drainage Design of Road.

Simulating the result of the drainage system design

Based on the analysis of the geologic conditions and the nature of the roadbed, the depth of the drainage pipes is 2.5m and the diameter as 0.5m, the depth of the seepage ditch is designed as 2m and breadth as 0.7m, the height of blind drains is designed as 2m and breadth as 1.5m. The gradient of the landslip beside the roadbed is 40°. The longitudinal length of the roadbed in the model is 300m. A 3-D finite-difference groundwater model is constructed to describe and predict the behaviour of the groundwater and the drainage systems. Spatial discretization of the model domain is controlled by the integrity of the landslip and roadbed.



(a)



(b)

(a) The plane design of the drainage pipes in the slope and roadbed
(b) The stereo design of the drainage pipes in the slope and roadbed

Figure 8. The simulation of the drainage system design

Table 2. The simulated results for roadbed drainage

Design scheme	Border of road				Centre of road			
	water head of raw 7	Water head of raw 8	Distance of raw 7and 8	water grade J1	water head of raw 13	water head of raw 14	distance of raw 13 and 14	water grade J_2
Without drainage pipes	44.3	36.8	12	0.63	43	35.6	4	1.85
With drainage pipes	10.3	9.3	12	0.08	10.3	9.2	4	0.28

The results are shown in Table 2 and Figure 8. The drainage system in the landslide accelerates the decline in groundwater level inside the roadbed and landslip, and reduces the hydrodynamic pressure. This indirectly diminishes the destructive function of the groundwater to the roadbed. The drainage design is critical for the half-excavated and half-filled roadbed.

CONCLUSION

The key factor in roadbed failures is, with seepage of rainfall into the unsteady slope, that the groundwater field changes, creating deformation both of the landslide and the roadbed. Based on the analysis, a drainage system in the sliding slope protects the roadbed in mountainous areas, and can effectively lower the groundwater level and inhibit water-induced failure of roadbeds. This system of drainage is recommended in all future highway schemes in such areas.

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