Application and seepage models of drainage inside a roadbed of an expressway in the west of China

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Abstract: The paper has summarized seepage models to evaluate the adequacy of performance design measures for interior drainage of expressway roadbeds, under different conditions of climate and landforms. The modeling is based on worst-case precipitation and also for design measures restricting infiltration. It has been proven by engineering cases that the drainage design seepage model is reasonable. Definite experiences of drainage design for blind drains inside the roadbed of expressways in the west of China have been put forward to support the technique of the blind drain.

Résumé: Le papier a récapitulé des modèles d'infiltration pour évaluer l'adéquation des mesures de conception d'exécution pour le drainage intérieur des assiettes de la route d'autoroute urbaine, sous différents états du climat et des formes de relief. Modeler est basé sur la précipitation des cas les pires et également pour la conception mesure limiter l'infiltration. On l'a prouvé par des cas machinants que le modèle d'infiltration de conception de drainage est raisonnable. Des expériences définies de la conception de drainage pour les drains aveugle à l'intérieur de l'assiette de la route des autoroutes urbaines dans à l'ouest de la Chine ont été proposées pour soutenir la technique du drain aveugle.

Keywords: highways; failures; environmental impact; highways; 3D models

INTERACTING OF ROADBED SYSTEM AND GEOLOGICAL ENVIRONMENT

Water constitutes the principal natural cause of damage to highways. Settlement, flushing, slumping, and pot-holing, all of those roadbed's diseases relate to forms of internal erosion of the road-bed subgrade by surface water or ground water. The degree and mode of roadbed damage varied with the character of different groundwater movement, as well as different geologic and rock conditions. The crevice is the main water source of mountainous areas, where the runoff gullies are well developed and rainfall can't infiltrate, so making surface water more abundant and ground water discontinuous. Where the ground is broken, it will be seen to contain plenty of ground water, especially at mountain fronts and at the toe edge of alluvial fans, where the sands vary from coarse to fine, and the ground water flows from fast to slow. So, in deep mountainous areas and at the top of the alluvial fans, debris flows, landslides, water seepage can easily break out; at the plain and the front edge of alluvial fans, pot-holes (dump-mortar), subgrade settlement, and road-boundary landslides can easily form. Where the roadway crosses areas of soft ground, weak rock units, shear zones and even interbedded soft and relatively hard rocks, roadway deformation, and landslides caused by underground water infiltration, all degrade the stability of soil body. Accordingly, it is very necessary to study drainage mechanics of various roadbeds.

ROADBED DEFORMATION CAUSED BY ACCUMULATED PORE WATER

Pore water accumulation in the roadbed can be divided into two cases: 1) hydrostatic uplift under pressure under excavation roadbeds, which receives rainfall alimentation from the watershed, and 2) the where aquifer head pressure rises and groundwater infiltrates the roadbed directly. Some emerging groundwater can flow into the upslope (excavated side) drainage ditch, but some ground water flows under the roadbed and into the mass of supporting downslope (stowed side) of the roadbed, softening the geotechnical characteristics of the compacted embankment. Then the filled ground happens to slide because of destabilization. In the second case, where the roadbed isn't affected by artesian pressure, atmosphere rainfall and surface water infiltrate into roadbed subgrade directly through potholes and fractures, moving downward along the border of system excavation and filling, raising the interstitial pore pressure increase, causing the whole embankment body into gravitational glide to the downslope (stowed) side of the roadway.

SENSITIVITY ANALYSIS OF GROUND WATER ELEMENT TO THE SLOPE STABILITY OF ROADBED

In the western mountains and hills of Chine, most highway roadbeds are constructed by cut-and-fill (dug and stowed), so the stability of the roadbed is very important for good maintenance. During the period of rain, those zones are easier to design for collection of surface water and diversion of ground water, than in more flat terrain. The control action of ground water to the stability of formation can use this formula to explain.

Adapting the Fellenius method of slope stability computation, we considered the effect of ground water on slope stability, through the mathematical formula of stability factor, as shown:

$$K=\frac{\sum[(W_i\cos\alpha_i - F_i\sin\alpha_i - V_i\cos\alpha_i - V_i^{'}\sin\alpha_i tg\alpha_i + \bar{h}_i\triangle h_i\sin\alpha_i)f_i + c_iL_i]}{\sum[W_i\sin\alpha_i + F_i\cos\alpha_i + \bar{h}_i\triangle h_i\cos\alpha_i]}$$

In that formula: W_i ---rock mass deadweight(10KN/m^2); V_i --- rock mass vertical-section thickness (m) , $V_i^{'}$ --- the volume of ground water in the rock or soil mass(m^3) , F_i ---earthquake equivalent horizontal static force(10KN), h_i --- average thickness of saturated ground (pore) water level(m), $\triangle h_i$ ---the up-and-down water-head of side slope(m), α_i --- dip angle of theoretical slide surface (^{o}), cohesion of base soil unitg (Kpa), f_i ---internal friction coefficient of roadbed mass base, and, L_i ---the length of slide face (m).

We then proceeded to make a parametric sensitivity analysis to test the effect of pore pressure as it affects the slope stability. This leads us to draw the relation curve of groundwater level and the resulting stability factor. Figure 1 indicates that, through lowering groundwater level of roadway embankment reduce infiltration flow of water (surface water or ground water) and increases the shearing strength of underlying rock mass, especially if there is a clay (argillization) interlayer, and the assurance coefficient of slope stability was increased.

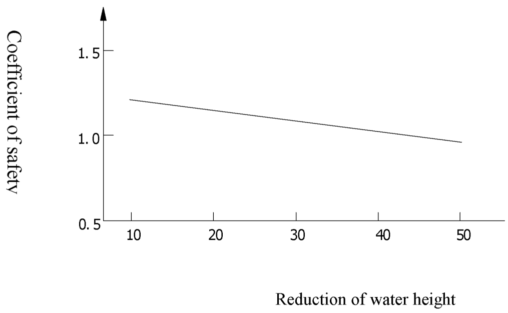

Figure 1. The relation between reduction of water height and coefficient of safety of slope

THE UNDERGROUND DRAINAGE FACILITY OF ROADBED

Pore water content of the roadbed slope is controlled by constructing weep holes and drainage blankets. According to different actions and working conditions, ground water facility of inner roadbed mainly can be divided into three types: 1) blind-ditch; 2) dry well; and 3), infiltration ditch. As per different structure of infiltration ditch it can be divided into infiltration ditch filled with gravel (named as blind drainage), tube-type infiltration ditch, and hole-type infiltration ditch; These three type infiltration ditches are made up of drainage layer, reversed filter, and top-most closing layer. Through investigation, in the drainage design of typical western road design, the weep hole is used for slope drainage, and the blind–ditch is mainly adopted to inner roadbed drainage.

THE MATHEMATIC MODEL AND ANALYTIC SOLUTION OF ROADBED DRAINAGE

The mathematic model of considering infiltration from continuous rainfall

Continuous rainfall causes infiltration to the vadose zone. If the infiltration capacity of rain is equal to that of the outward water discharge, the movement of pore water in the roadbed can be considered as steady flow, such as with the layout of blind-ditch like Figure 2. Therefore, the mathematic model of the movement underground can be shown by formula (2-1):

$$\left.\begin{aligned} &K\frac{d}{dx}(h\frac{dh}{dx})+W=0 \\ &h\big|_{x=0}=h_0 \\ &h\big|_{x=L}=h_0 \end{aligned}\right\} \qquad (2\text{-}1)$$

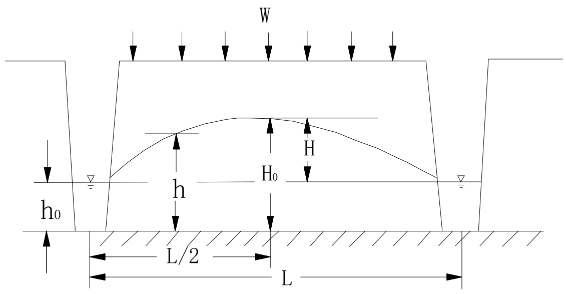

Figure 2. The lay of blind channel

In that formula(2-1)take h that is in the differential as average value $h_m, h_m = \frac{1}{2}(H_0 + h_0)$, meanwhile the equation can be simplified :

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

The result is :

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

In that formula (2-2): h_0 ---stream current depth in the blind-ditch (m), W ---influent strength, K --- permeability coefficient of aquifer (m/s), L ---space length between ditches (m).

Formula (2-2) is used to draw infiltrative curvilinear equation among the blind-ditches. The water height is the maximum in the middle of blind drainage when $x = L/2$, meanwhile the maximum of water height is $h_{\max}$, generally it can be expressed by the middle water height h_0:

$$h^2{}_{\max} = H_0^2 = h_0^2 + \frac{WL^2}{4K} \qquad (2\text{-}3)$$

From formula (2-3), the space length *L* of blind -ditch can be worked out under the infiltration condition:

$$L = 2\sqrt{\frac{K}{W}(h_{\max}^2 - h_0^2)} \qquad (2\text{-}4)$$

The mathematic model after long-term rainfall

At the flood times, because of long-time rainfall, the water height among blind-ditches rise, and possibly becomes close to the ground surface. After rainfall, ground water in the ditch is discharged rapidly, and falls to original water height, but the ground water among the ditch can't restore at once, and remains still close to horizon. Meanwhile the water height as initial H_0, the water height in ditch is h_0, stop rainfall $W = 0$, so at this time the mathematic model of groundwater movement can be shown as follows:

$$\left.\begin{array}{ll} K\frac{\partial}{\partial x}(h\frac{\partial h}{\partial x}) = \mu\frac{\partial h}{\partial t} & (0 < x < L, t > 0) \\ h(x,0) = H_0 & (0 < x < L) \\ h(0,t) = h_0 & (t > 0) \\ h(L,t) = h_0 & (t > 0) \end{array}\right\} \qquad (2\text{-}5)$$

Take *h* in the differential as average $h_m = \frac{1}{2}(H_0 + h_0)$, and identify $a = \frac{Kh_m}{\mu}$ (m^2/d), then use the transformation of Laplace to work out the result (2-5):

$$h - h_0 = H[1 - G(\bar{x}, \bar{t})] \qquad (2\text{-}6)$$

In the formula(2-6): h ---the water height value of underground at random dot and time among ditches(m), H ---difference of water head ,which the value is $H = H_0 - h_0$, $G(\bar{x},\bar{t})$ ---coefficient, the follow series present its value is:

$$G(\bar{x},\bar{t}) = 1 + \sum_{n=1}^{\infty} (-1)^n \frac{2\cos[(1-\bar{x})\frac{(2n-1)\pi}{2}}{\frac{(2n-1)\pi}{2}} e^{-[\frac{(2n-1)}{2}]^2 \cdot \bar{t}} \qquad (2\text{-}7)$$

In the formula(2-7): $\bar{t}$ ---relative time, $\bar{t} = \frac{4at}{L^2}$; $\bar{x}$ ---relative distance, $\bar{x} = \frac{2x}{L}$.

Now formula (2-6) is the infiltrative curvilinear equation among ditches. when $\bar{t} > 0.3$, the series only need to take the first item, $n = 1$, at the middle point of the infiltration ditch that is $x = L/2$ the water height value is $h = h_1$,and use $\bar{x} = \frac{2x}{L} = 1$ to substitute (2-6),take logarithm and sort it out:

$$L = \pi \sqrt{\frac{Kh_m t}{\mu \ln \frac{4H}{(h_1 - h_0)}}} \qquad (2\text{-}8)$$

Under this condition the water flow of infiltration ditch

$$q = K \frac{h_1^2 - h_0^2}{L} \qquad (2\text{-}9)$$

In that formula: h_1 ---the water height in the ditch at *t* time, μ ---the feed degree of underground reservoir; t ---the calculation time, the other signs are the same to before.

Simulation of the effect of drainage on roadbed stability

Drainage effect is simulated with Modflow software by giving different values of hydraulic conductivity, Permeable coefficient, intensity of rainfall and initial Hydraulic head of the system, and so on. Then proceed analysis to these element's sensitivity.

CASE STUDY

Engineering survey

"B" contract segment of Chongqing Wanxian-liangping freeway crosses through the landslide trailing-edge of the Tang family's farmyard, which is part of the cut-and-fill roadbed. When the fill becomes loose, under continuous rainfall, slope destabilization and sliding deformation damage is created at this segment, and landslide body and border appear noticeable by multiple open fractures, which make a hazard to the freeway operation. Design actions, such as blocking, cutting, draining surface water and ground water are available to act against the landslide. It is appropriate to construct a side ditch to discharge pore water in the cut-slope and also under the embankment pavement. Also endwise blind-ditches and crosswise blind-ditches can be installed to discharge pore water accumulated within the roadbed, with catch drain to collect and remove surface water of the side slope, and also weep holes to discharge underground porewater in the side slope.

Analysis on influencing factor of drainage effect

According to formula (2-8), the changeable relation curve of space length *L* and drainage time *t* of blind-ditch can be helpful, as shown in Figure 3. From formula (2-8) we can further derive the formula dealing with the relation of water height drop h_1 to the drainage time *t,* for the middle position, between blind-ditches, and then draw the curve of changeable relations, as in Figure 4. From formula (2-8), (2-9), the changeable relation curve of blind-ditch unit discharge water *q* altering with drainage time *t* can be shown, as Figure 5.

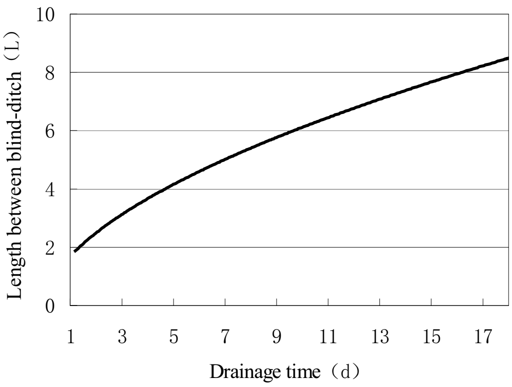

Figure 3. The curve of relation of *L* and t

From Figure 4 we know that, if we want to drop the porewater level in roadbed, into the required safety range, we must design a greater drainage time, and then the space length between blind-ditches also can be enlarged properly. From Figure 5 we can see, porewater surface in the blind-ditch is higher, and then its water discharge is greater. As time increases, the drainage water gradually reduces, and the descending speed of porewater reduction gradually slows. When we set the space length at 8 m, when water height per unit length blind-ditch is the highest, the maximum of drainage water can reach 1.0m^3/d in roadbed. The maximum of drainage water can meet to specification standard. Within sixteen days after the rainfall stopped, drainage system can drop the porewater level in the roadbed to design value of safety.

Simulation on drainage effect of blind-ditches

Through using the geomechanics parameter of the geotechnical body and design drainage system as to terminal condition that is mentioned above, the roadbed and roadbed side slope can be generalized to the mode field of the three-dimensional simulation. In the model, there are 2 endwise blind-ditches and 2 crosswise blind-ditches, and 9 weep holes. Within sixteen days after the rainfall stopped, drainage system theoretically can reduce the porewater levelin the roadbed to safe design value. The slope grade of excavation side (not stabilize side slope) is about 40 degrees, the wide of roadbed is 24.5meters, the length on the endwise is 125 meters, about 60 meters cross slope body. The divergence of the roadbed in the space contain of mesh subdivide of the flat face and mesh subdivide of the vertical:

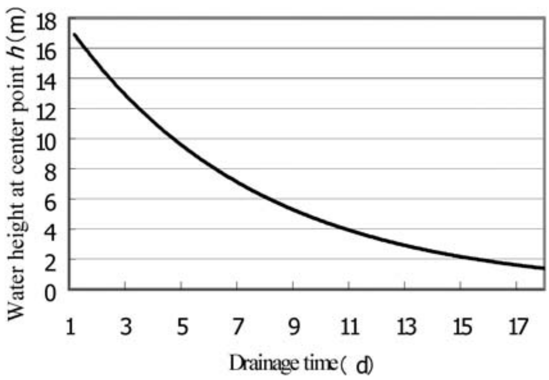

Figure 4. The curve of relation of *h* and *t*

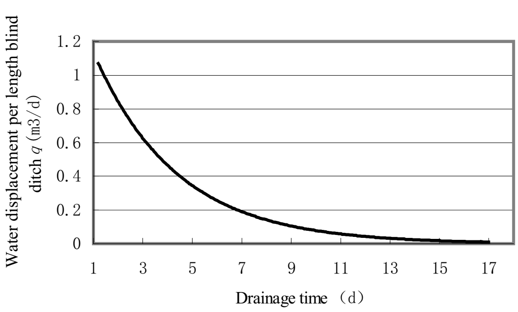

Figure 5. The curve of relation of *q* and *t*

There are 19*22 meshes on the flat in all. According to the layout of drainage facility, divided 10 layers on crosswise, split 2090 elements in all. Weep holes, infiltration channel, and blind ditch are located in the fourth, sixth and ninth layers respectively. Both sides of the infiltration channel are regarded as a fixed-head boundary, and upward of the fifth layers of roadbed are regarded as invalid (non-affecting) head units, and the others are seen to be effective units. The achievement of three-dimensional simulation is shown in Figures 6 and 7 and Table 1.

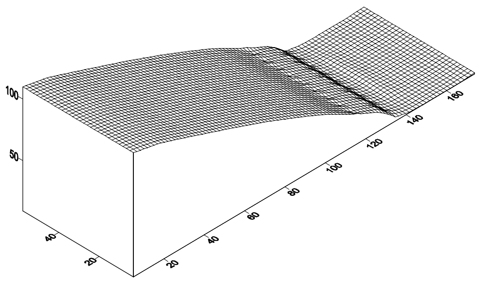

Figure 6. The simulation of drainage effect of slope

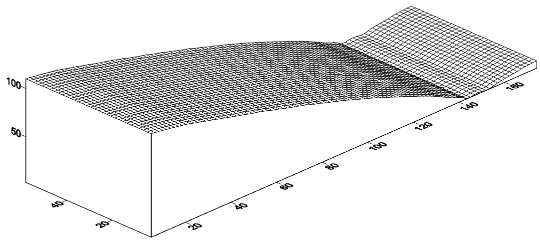

Figure 7. The simulation of drainage effect of blind channel

From Figures 6 and 7, and Table 1 we can see that the porewater head in the slope becomes reduced to 21m, from the original 33.2m at position of the roadbed joining. These porewater levels are reduced to 3.1 meters at the middle of roadbed, and the porewater glow gradient reduces to 0.25 from 0.94, making a safe drainage effect apparent. The obvious watershed is formed between two blind ditches and weep hole, and the purpose of drainage is achieved. Therefore, the drainage design of Tang jiayuan's landslide roadbed and slide slope is reasonable, and the porewater height can be naturally reduced to design requirement after each rainfall, all by the internal drainage system installed at time of construction.

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Table. 1 The production of simulation of the dimension seepage inside roadbed of Wan-Liang highway in Tang Jiayuan

Program	The position which the side slope combine to the roadbed				The middle position of the roadbed			
	The seventh of water head (H_1)	The eighth of water head (H_1)	Level Distance between two points (L_1)	Water grade (J_1)	The fourteenth of water head (H_3)	The fifteenth of water head (H_4)	Level Distance between two points (L_1)	Water grade (J_2)
P=80 α=0.02 k=0.1	33.2	21	13	0.94	3.6	3.1	2	0.25

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