Prediction of bank instability on the Yuhuai Railroad in the Three Gorges reservoir area

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Abstract: The Chongqing-Huaihua railway links Jiangbei in Chongqing and Huaihua in Hunan Province from north to south. It passes through Fulin, Qianjiang and Tongren in Guizhou Province. The length of the Yuzui-Fulin section, in the Yangtze River valley, is 79.6km and the length of the Fulin-Tukan section, in the Wu River valley, is 56km. A two-section method has been used progressively to analyze the line and areas of potentially eroding reservoir banks. The steady underwater angle between normal flood level of the Three Gorges reservoir and normal water level of Yangtze and Wu River, and the steady angle of the water level above normal flood level of the Three Gorges reservoir have been used to analyze the impact of erosion on unfavourable geology, in particular ablation of breccia. In order to guarantee the safety of the railway, tunnels have been used to by-pass areas of potentially serious bank caving but areas with less serious potential have been treated through engineering works.

Résumé: Le chemin de fer de Chongqing-Huaihua, le début nord est de quartier Jiangbei de la ville Chongquing. Traverser Fuling, Qianjiang et Dongren de Guizhou, le final est de Huaihua de la Province Guizhou. Dont la section de Yuzhui-Fulin se trouve dans la valée de la fleuve Yangtzé. Sa longueur est de 79.6KM. La section de Fulin-Tukan se trouve dans la valée de la fleuve Wu. Sa longueur est de 56KM. Le texte analyse progresivement avec la méthode de deux sections la ligne de la kofelsite, de l'impactite et la région de la kofelsite et de l'impactite. On choisit l'angle stable entre le niveau d'eau permanent de la fleuve Yangtzé, la fleuve Wu et le niveau d'inondation permanent du réservoir de trois gorges. On choisit l'angle stable sur la rive au dessus du niveau d'inondation permanent dans le réservoir de trois gorges. On analyse approfondement le remous qui influence à la géologie mauvase et à la brèche dissolu de sel. Pour assurer la sécurité du chemin de fer, selon le niveau de l'impactite du remous du réservoir de trois gorges à la rive, on fait la mesure relative pour le traitement. Pour le gravement de l'impactite du remous de réservoir, le traitement difficile des travaux, la région du danger latent possible, on choisit la mesure du détour ou du tunnel. On fait la mesure du traitement des travaux pour la région de la kofelsite moins grave.

Keywords: reservoir ; slope; prediction of the sloughing; remedial works; Three Gorges; Yuhuai railway

INTRODUCTION

The Chongqing-Huaihua railway links Jiangbei in Chongqing and Huaihua in Hunan Province from north to south. It extends through Fulin, Qianjiang and Tongren in Guizhou province.

The Yuzui-to-Tukan section is located in the Three Gorges Reservoir area. The section between Yuzui and Fulin , in the Yangtze River valley, is 79.6 km long with the river valley at 200-300 m high and the overall relief of 500-800 m. The route consists mostly of roadbeds and bridge projects. Parts of the lower hilly areas are passed by tunnels, the principal of which are Huangjia Wan Tunnel and Jiepai Po Tunnel.

The Fulin-Tukan section, located in the Wu River valley, is 56Km long. The ridges at both sides of the section are 500-800m in height, the relief ratio is 200-500m, and the overall natural slope is 30-50°. The bank slopes are steep, locally with cliffs. The river valley is narrow and deeply incised. The longitudinal slope of the river bed is sharply steep. The line passes this area mainly via bridges and tunnels. There are 14 tunnels, such as the Fulin Tunnel, Moxi 1#and 2#, Baishatuo 1#, Zhicheng, Baima 1#and 2#,Yangjiaoqi, Yangjia Dam Tunnels. These total about 36.8Km long, some 66% of the route.

OUTLINE OF THE GEOLOGICAL ENVIRONMENT

The Yuzui-to-Fulin section, located in part of the Yangtze River Valley, is cut through the main red beds of the Upper Jurassic Suining Formation, Middle Jurassic Shangchaximiao, Xiachaximiao and Xiantian Formations (J2x), and the Middle to Lower Jurassic Ziliujing Formation (J1z). The red beds consist of interbedded purplish red mudstone, yellowish green sandy mudstone, and siltstone, intercalated with medium thick-bedded limestone, and quartzose sandstone which is locally thickly bedded to blocky in character. Bedrock is mainly exposed on the two flanks of the route where superficial deposits are thin. Lenses of soft soil are scattered on lower ground and colluvial boulder soils occur at the toes of steep rock slopes. The geological structures trend NE or NNE, almost parallel to a set of long symmetrical folds that are arranged en echelon. The main structures are the Mingyue and Huangcaochang

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anticlines and the Jianshanpo fault system. Some parts of the railway line intersect with the structural trend at a large angle but the section of the line from Taihong to Changsou is parallel to the structural trend.

The Fulin to Tukan section, in the Wu River valley, mainly passes through the Middle Leikou Slope Formation, Lower Jialing River Formation and Feixianguang Formation of the Triassic system; the Upper Changxing, Wujiaping, Lower Maokou, Qixia, and Liangshan Formations of the Permian; and the Middle Hanjiadian Group, Luoreping Group, Lower Luoreping, Xiaoheba, and Longmaxi Formations of the Silurian. The Triassic and Permian strata are mainly purplish red limestone, yellowish green mud rock, shale, and the breccias of the Jialinjiang Group formed through dissolution of salt. The Silurian strata are mostly yellowish green, grey yellow, and purplish red shales, and pink sandstone interbedded with mudrock. The main geological structural trend is approximately NNE consisting of parallel folds and associated fractures. The fold structures include the Xinli, Tudiya, Danzishan, Jinzishan, Tongmawan, Baima and Yangjiao anticlines. The railway line meets the structural trend at a large angle. There is poor exposure of bed rock due to slope instability, talus, accumulated rock debris and salt-dissolution breccia. In addition, the route has passed some relatively large-scale slopes like those at Xiaoxi, Yangjiaopo, and Tukan slope groups.

OUTLINE OF BACKWATER IN THE THREE GORGES RESERVOIR

The Three Gorges Reservoir is the most famous water resource and hydropower project under construction in the world. It is a typical river valley reservoir with total storage capacity of 393,108 m^3, installed capacity of 17.68 million Kw, annual average power generation of 84 billion Kwh, a normal storage level of 175 m, and is 185 m in height. The tail water of the Yangtze River runs to Tongguanyi in Chongqing, and the tail water of Wu River runs to Tukan Town. The upstream elevations of the Wu River segment of Yuhuai line are shown in Table1.

Table 1. The reservoir water level in Wujiangkou-Tukan

Name of cross section	Distance between estuary	0.33% flood level silting for 100 years (m)	1% flood level silting for 100 years (m)	10% flood level silting for 100 years (m)	0.33% flood natural water line (m)	1% flood natural water line (m)	Corresponding railway mileage (Km)
Mouth of Wujiang River	0.00		183.36	179.56	171.80	167.16	
Wujiang Bridge, Fuling	7.5	189.25	184.54	181.25	177.09	172.38	DK137
Machikou	10.2		184.96	181.86	179.00	174.26	DK140
	17.5		187.24				DK146
	19.0		187.71				DK147
Wangbeituo	22.7		188.86	185.86	187.50	182.86	DK151
Yajiangkou	31.4		192.86	189.36	192.00	187.26	DK159
	38.5		196.04				DK166
	40.0		196.71				DK168
	43.8		198.41				DK173
Baima Town	44.8		198.86	194.86	200.60	196.36	DK174
	46.3		199.57				DK175
	50.0		201.34				DK177
Tukan	61.6		206.86	201.86	211.00	206.86	DK188

PREDICTION OF BANK INSTABILITY IN THE RESERVOIR AREA

Principles for assessment of slope bank steady angle and design of roads and bridges

Determination of slope bank steady angle

A two-stage method was used to predict sloughing from the bank of the reservoir. The first used the underwater steady angle between normal flood level of the Three Gorges reservoir and normal water level of the Yangtze and Wu Rivers. The second used the steady angle of the up-stream slope above the normal flood level of the Three Gorges reservoir. These two angles were determined according to the method set out in the Geological Institute of First Railways Surveys and Design (1999) and the Study Report on the Prediction Method for Reservoir Bank Caving of the Waifu Reservoir by the Second Survey and Design Institute. The side-slope ratio was also investigated. The various lithologies comprising the bank slope steady angle are shown in Table 2.

Table 2. The stable slope angle in the water and stable slope angle ratio above the water

Name of rock	Material composition and character	Slope angle of underwater steady bank	Slope ratio of above-water steady bank
Salt dissolution breccia W4		34-36°	1:1
Powdery fine sand	Dense e<0.6	18-21°	1:1.5
	Medium dense e 0.6-0.75	15-18°	1:1.5
	Loose e>0.7	12-15°	1:1.5
Medium and thick sand	Dense e<0.55	21-24°	1:1.5
	Medium dense e0.55-0.65	18-21°	1:1.5
	Loose e>0.65	15-18°	1:1.5
Glutinous soil	Dense e<0.6	24-27°	1:1.25
	Medium dense e 0.6-0.9	21-24°	1:1.25
	Loose e>0.9	18-21°	1:1.25
Glutinous soil with detritus	Stone content>35%	27-30°	1:1.25
	Stone content 20-35%	24-27°	1:1.25
	Stone content<20%	21-24°	1:1.25
Reduced stone	Stone content>70%	33-36°	1:1.25
	Stone content 60-70%	30-33°	1:1.25
	Stone content<60%	27-30°	1:1.25
Float stone	Full cementation	40-45°	1:1
	Half cementation	34-36°	1:1

Principles for design of the roadbed near the sloughing bank of the reservoir

The key priority is to protect the safety of route. Matters to be considered construction of:

- walls, verging sections of the line that have a thin cover layer, based on bedrock;
- pile foundation trimmer retaining walls or buttresses where cover is thicker;
- reinforced or reserved cladding, compaction within buttressing, and side grouting

in relation to poor ground conditions influencing the route.

Principles for the design of bridges near the eroding bank of the reservoir

Some bridges required digging or piling of foundations to bedrock below the line of sloughing bank depending on the landform and geological conditions.

Prediction and principle of sloughing bank

Thirty nine geological cross sections were made according to the conditions on each segment of the railway. These were based on 72 boreholes per 1614 metres. The two-section method was used to determine the potential areas of sloughing. Where reservoir sloughing was predicted to be serious, or other problems may exist, tunnels are used to avoid potentially unstable banks, for example, the Baishatuo 1# tunnel (3.91km long). In sections where sloughing is mild, the sections of line are treated by engineering works. The nature of each segment and the measures adopted are described in the following paragraphs:

(1) DK65+317-DK66+140 Segment: this is hilly, with a general cross-route gradient of 15°-25°, and 205.92m in height. The stratum is J1-2z-J2z mudstone, sandy rock or limestone. The bedrock has thin cover. The lake of the Three Gorges Reservoir is 192.84m high. There are two landslides in the segment at DK65+410-+450 and DK65+610-+650. These will be induced, allowed to recover and repaired by butressing.

(2) DK137+190-+640 Segment: The elevation of the Fulin Wu River Bridge is 216.57, falling to 184.54m below the usual level of the Three Gorges Reservoir. The exposure bedrock is T1j thick bedded limestone. In the ChongQing terminal, there is residual diluvium and collapsed diluvium layers which will be susceptible to sloughing. The protective engineering measures are rock bolting, and shotcreting with wire mesh.

(3) DK145+835•DK159+187 Segment: The route runs along Wu River. Most of the segment is hilly, with a general cross-line gradient of 10-30°. The centre of the channel and banks of the Wujiang River are covered by thin soil and thick weathered salt dissolution breccia. The bedrock in this part of the route is T2l limestone and marl, T1j limestone intercalated with salt-dissolution breccia, 216.25-223.05m high reduced to 188-191.83m after unusually high flooding in the Three Gorges Reservoir. Geological faulting influences the Yangjiawan Middle Bridge, Xinkaitan Bridge, Mayan Dam Middle Bridge, Liangshuijing Bridge, Caojiatang Bridge, Nishizi Bridge, Ganbao Bridge and the roadbed of the DK158+260-+770 segment. Bedrock in the bridged areas is beneath the erosional bank. The right side of the DK146+308.93-+536.95 segment was buttressed. Anchor piles were embedded on the right of the DK158+262-

+731.56 section which was reinforced by soil compaction and side grouting. A pile foundation trimmer retaining wall was constructed on the right of D1K158+732.56-+779.56.

(4) DK162+971-DK164+350 Segment: the route runs along Wu river gorge with a general cross-line gradient of 30-40°. Soil is 2-15m thick. Bedrock is S shale or sandy rock. The height above water level is 215.50m reducing to 194.5m after unusually high flooding of the Three Gorges Reservoir. The influence of geological faults on sloughing is predicted to be relatively serious. A pile foundation trimmer retaining wall is set on the right of DK163+596-DK164+049.5 and is reinforced by soil compaction and side grouting. A balance weight verging wall is set on the right of the DK163+596-DK164+049.5 and DK164+250-+350 segments.

(5) DK164+350-DK174+743 Segment: The route runs along Wu River gorge and has a steep natural cross section. It is covered by thin soil and much bedrock is exposed. Tunnels are the main feature of this section except for bridged sections at Jiaobanggou. The stratum is T1f muddy bedded limestone or T1j salt-dissolution breccia. The elevation of the line is 215.5-231.46m changing to 194.5-200m after unusual high flooding of the Three Gorges Reservoir. The central Jiaobanggou channel has a thick cover layer which is liable to sloughing therefore pile foundations are taken below the bank line.

(6) D1K174+743-D1K176+270 Segment: the route runs along Wu river gorge. The general cross sectional gradient of 20-35°. Bedrock is covered by 1-12m thick soil. The bedrock is T1f muddy bedded limestone mantled by detritus and boulders of slope diluvium, and collapse diluvium, with a maximum thickness of 20m. The elevation of the line is 210.706m reduced to 200.2m after flooding of the Three Gorges Reservoir. It is predicted that bank sloughing on the DK174+770-+910 (Baima three line bridge) and DK175+400-+931 segments will be relatively serious. Bridge foundations are therefore taken below the level of the sloughing bank by the pile foundations. A balancing verge wall is set on the right of DK175+425.8-+883 and a pile foundation trimmer retaining wall is set on the right of DK175+883-+931.

(7) DK176+270-DK188+600 Segment: the route runs along Wu river gorge. The general cross sectional gradient of 20-40°. Bedrock is P1m+q limestone, S shale, sandy rock, and shaly limestone. Most of the works are tunnels, totalling 9.758Km in length. Bridges and roadbeds are limited to Yanghjia Dam and Tukan stations. The elevation of the line is 215.86-226.60m falling to 200.2-206.86m by the Three Gorges Reservoir. The sloughing bank of the reservoir has no influence on the tunnels but it is predicted that bank sloughing on DK183+100-+450 will be serious. A balancing verge wall is used on DK183+093-+372, a pile foundation trimmer retaining wall is set on the right of DK183+372-+428, and a balance weight verge wall on the right of DK183+428•+445. The Yangjiaozai and Zhichang landslides will be induced following which a combination of buttressing and slope surface protection will be used.

EFFECT OF FILLING OF THE THREE GORGES RESERVOIR ON WEAK STRATA AND SALT-DISSOLUTION BRECCIA

Effect of reservoir backwater on poor geological body

(1) Ganbaogou landslide is located in the DK146+330-+470 segment. It is 144 m in length, 135 m in width and 4-14 m in thickness. The route passes across Ganbao Bridge in the middle-back part of the landslide. Bedrock cliffs are exposed at the back scar above a small landslide slope, and rock is exposed at the toe. The sliding materials are detritus and boulder soil, cut by two channels but without any issues of groundwater. The landslide was induced by quarrying. At present, it is stable. After filling of the Three Gorges Reservoir, the lower part of the landslide will become flooded with a risk of further movement. The landslide will be induced and then buttressed.

(2) Nuomixi landslide: The landslide is leaf shaped. The axial length is about 400m, the width 150-300m, and the thickness 4-25m. The material displaced in the slide is mainly boulders in soil, but with some salt dissolution breccia.. After filling of the Three Gorges Reservoir, the lower part of the landslide will be flooded. The route passes from the back edge of the landslide with the section from Huaihua terminal of Nuomixi Bridge and over 20m away from the entrance of Yangjiaozai tunnel on the landslide. In order to guarantee the operation of railway in safety under the landslide will be induced and will then be reinforced by buttressing and treatment of the slope.

(3) Zichang landslide: the landslide is located in the DK186+980-DK187+360 segment of the route. It consists of a main landslide and an associated incipient landslide. The plan of the main landslide is pear shaped. The axial length is 540 m long, the width 100-500 m wide and thickness 10-36 m thick. The total volume is 2.4 million cubic metres. The landslide slips towards Wu River. The incipient landslide, located to the right of the main landslide, is 12 m long, 200 m wide and about 10 m thick. The direction of movement is towards a branch channel almost across the direction of the main landslide. Most of toe of the landslide is clay soil, while the back scar is mainly in boulder soil. From recent investigations, the slope is at present in a creep phase, and serious surface fractures develop after each rainy season. After filling of the Reservoir, the stability of the landslide will worsen. The line passes along the back edge of the landslide. The Yangjia Dam Tunnel portal and Zhichang Three-Line Bridge are on the landslide where some piles are emplaced to reinforce the sliding body.

Effect of reservoir backwater on salt-dissolution breccia

T1j salt-dissolution breccia is extensively distributed within 5Km of Baitao in the Wu River Valley. The breccia is light grey or purplish red. The long axes of the clasts are at right angles to the bedding and these vary in diameter to maximum of 1.5 m. The clasts are mainly limestone or dolomite, generally in an argillaceous sandstone matrix, and appear to be a detrital or boulder soil. The weathered beds can exceed 20 m in thickness. The engineering geological properties of these are poor so they are likely to erode easily when the reservoir has filled.

CONCLUSION

The Yuzui-to-Tukan section of the Huaihua railway is located in Yangtse and Wu River Valleys, behind the Three Gorges Dam. Geological surveying determined the distribution of weak geological strata. A two-section method was used to predict the scale of bank erosion and its potential effect on the railway. Engineering measures have been designed to guarantee the stability and safety of the railway.

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