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QINGHAI-TIBET RAILWAY, CHINA AND THE SOLUTIONS TO ITS MAJOR GEOTECHNICAL PROBLEMS FOR CONSTRUCTION

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ABSTRACT

The Qinghai-Tibet Railway (QTR) is the highest-elevation one for passenger trains in the world and the first railway to connect central China to Tibet. Construction of this railway starting in 2001 had to contend with major geotechnical challenges, such as permafrost, environmental protection and seismic hazards. Its completion in 2006 is a remarkable feat in the world's railway construction history and crystallization of wisdom of human beings. In this paper, the planning and preparing history and the construction project of QTR are introduced. The major three thorny problems, permafrost, lack of oxygen and environmental frangibility for the construction and their solutions are presented, which are active methods of riprap roadbeds, heat pipe roadbed and bridges over land for permafrost, health care system for lack of oxygen and environmental protection measures for construction and operation. Seismic safety assessment was carried out for earthquake damage mitigation of the railway. The laboratory test, field test and observation, and it's operation have shown that design, construction, and measures for earthquake hazards mitigation and environmental protection of the Qinghai-Tibet Railway are completely successful.

INTRODUCTION

China made history on July 1, 2006, when the Qinghai-Tibet Railway (QTR) was put into test operation. QTR is the highest-elevation railway for passenger trains in the world and the first railway to connect central China with Tibet, providing a direct tie between Tibet and other partitions of China with more economic, cultural and political significances. Stretching about 1,142 km, it runs from Golmud in Qinghai province to Lhasa, the capital city of the Tibet Autonomous Region, China (Fig.1).

Early in 1956, China government prepared to construct QTR, which begins at Xining, the capital of Qinghai province, ends at Lhasa. However the great project had to be laid aside because of the financial problem in 1961. And then, China aspired after putting it into practice, the second time in 1974, but it was stopped in 1978 due to three insoluble problems at that time, i.e. permafrost, lack of oxygen and environmental frangibility. It was the third time that China government put the issue of QTR construction on the table in 2000 while the country's economy had grown dramatically and Chinese scientists and engineers had accumulated enough data both in field and laboratory for 40 years before 2000 to design and construct QTR across the permafrost areas on the Qinghai-Tibet Plateau (QTP). After more than one year preparing, the project started in June 29, 2001 and completed in June 30, 2006.

Fig. 1. Sketching line of QTR (http://www.yahoo.com, edited).

Completion of QTR project is a remarkable feat in the world's railway construction history and crystallization of wisdom of Chinese scientists, technicians, workers and managers. It would benefit a lot to all ethnic groups in Qinghai province and the Tibet and speed the economic growth and social development in this area significantly.

In this paper, the great project of QTR, the three major thorny problems and their solutions as well as earthquake hazards mitigation for the railway are introduced in details.

THE PROJECT OF QTR

QTR traverses the spectacular topography of Qinghai-Tibet Plateau (QTP), cutting across four mountain chains – Kunlun, Fenghuo, Tangula and Nianqintanggula – where elevations of the trackbed are all above 4,600m. It also crosses five major rivers, the Yellow River, Yangtse River, Mekong (Lancang) River, Nujiang River and Lhasa-Brahmaputra River, and passes through the National Natural Protection Region of The Three River Sources. And most sections of it is above 4,000m in elevation, and 50km is above 5,000m. (Fig.2)

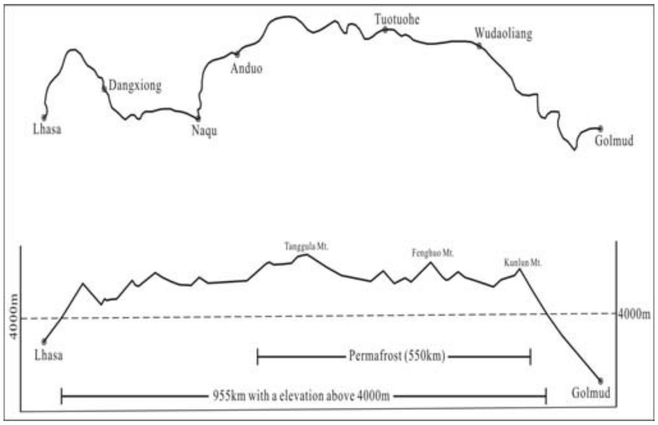


Fig. 2. Elevation and route of QTR.

The whole QTR consists two extensive sections. The first section of QTR from Xining to Golmud is 814km long, which has been operated since 1984. The second section from Golmud to Lhasa is about 1142km long, which was started to construct in June 29, 2001 and opened to transportation in July 1, 2006. Construction of the railway had to contend with major geotechnical challenges, permafrost, environmental protection, seismic hazards and variable hydrologic conditions.

The major reasons causing the geotechnical engineering problems are the special harsh climate and the change of microtopography, sand blown by wind, and hydrologic conditions under engineering construction. So it is important to pay more attention to engineering geological conditions, apply the dynamical design and optimizing enhancing intension design to constructing QTR.

The railway crosses the largest area of low-latitude permafrost in the world, in which there are 546.41km locating at continuous permafrost areas. There are total 10 tunnels, 9518m long, in QTR, of which 2 tunnels locate at permafrost areas, the elevations of 7 tunnels are above 4000m, the Fenghuo Mountain tunnel is the highest elevation tunnel of the world, 4905m above sea level, and the Yangbajing tunnel is the longest one along QTR, 3345m. Bridges with a total length of 159.88km are constructed along QTR, in which 451 bridges, a 120.28km length, locate at permafrost regions and the highest one is Sancha River Bridge, which is 54.1m high, and the longest one is Qingshuihe Bridge, which is 11.7km long (Fig.3). The elevation of the highest place of QTR is 5072m, which is also the highest point of railroad all over the world. The Tanggula station, 5068m, is the highest railway station in the world.

There are total 24 institutes and colleges, more than 100 permafrost scientists and 200 geotechnical engineers, 4 design institutes, 25 construction companies and 13 supervision companies, around 36,000 workers and managers took part in construction of the QTR project.

Fig.3. The Sancha River Bridge (left) and the Qingshui River Bridge (right).

Passengers can begin this train trip respectively in 7 cities, Beijing, Shanghai, Guangzhou, Chongqing, Chengdu, Lanzhou, Xining and then end in Lhasa. From Beijing, the capital of China, to Lhasa, it's a journey of 4,064Km, and the tour time is only 46 hours and 30 minutes. QTR trains are grouped by 14 cars and 2 locomotives, and the seating capacity is 936 persons. Every passenger on the train is given an oxygen mask to alleviate symptoms of altitude sickness. The oxygen pressure in each car is monitored, and cars are also equipped with a digital display that gives continuous updates of elevation, train speed, outside temperature and distance to the next station.

THE MAJOR THREE THORNY PROBLEMS AND THEIR SOLUTIONS

The permafrost, lack of oxygen and environmental frangibility are three thorny problems for construction of QTR across QTP. How to keep the stability of embankment in permafrost regions is the most serious scientific and technical challenge for scientists and engineers, because of the influences of thermal variations due to the artificial disturbance during construction of QTR and the increase of environmental temperature in the future.

Permafrost

QTR crosses 546.41km continuous permafrost regions, 82 km discontinuous permafrost regions, and the regions where annual average ground temperature above -1.0□ occupy 275km, high-contained ice regions 221km, high temperature and high-contained ice section about 134km (Fig.4). The permafrost is a very special soil, and it is quite sensitive to temperature, and other characteristics, including physical, chemical, and engineering features, are unstable and nearly correlative with temperature (Fig.5). Moreover, the characteristics are also influenced by the ice content, which is directly correlated to temperature and decreases with the rising of temperature (Xu, 2001).

As a result of the influences of global climate warming and railway engineering on the permafrost degradation, stabilizing permafrost is the most pervasive challenge for both construction and maintenance of the railway. Protecting the permafrost is a key to preventing embankment and roadbed failure from frost heaving and thaw collapse, the two main roadbed diseases from the degradation of permafrost. If the permafrost absorbs thermal energy that is not dissipated, then the permafrost will melt and the roadbed will be damaged.

Methods. Several active methods are developed and taken to protect permafrost along QTR, which include 3 three kinds of riprap roadbeds (namely ripped-stone embankment (116.07km), ripped-stone protect slope roadbed (156.21km), and U-shaped combination roadbed (or the multi-roadbed)), heat pipe roadbed (30.38km), bridge on land (bridge instead of roadbed, 451 bridges, 120.28km), and other assistant methods, such as, the ventilated-pipe roadbed, the awning roadbed, the heat preservation materials and heat pipe multi-roadbed etc. They have been applied in engineering design and construction. (Fig.6)

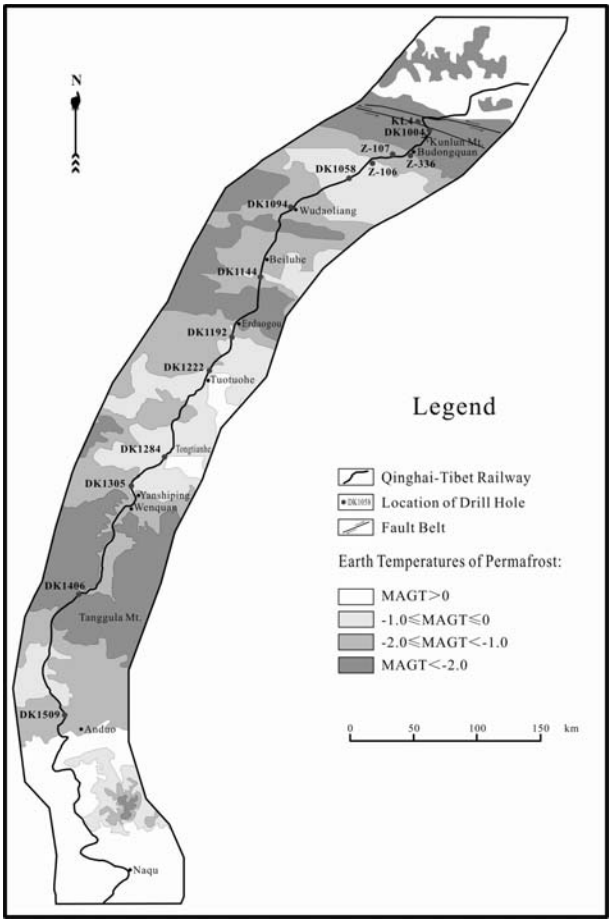


Fig. 4. The distribution of ground temperature of the permafrost and boreholes along QTR.

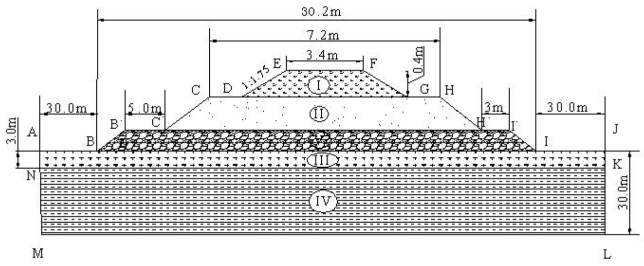
Fig. 5. The ice in the permafrost (by prof. Ma Wei).

Fig. 6. Examples of Engineering Measures Applied in QTR.

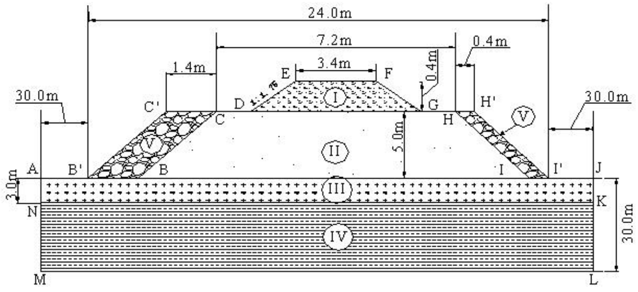
(1) Riprap Roadbed: This kind of measure includes ripped-stone embankment, ripped-stone protecting slope roadbed, and U-shaped combination roadbed (Fig.7). Most of the embankments and roadbeds are protected with "riprap", which are coarse, angular pieces of rock used to stabilize the surface. The riprap-engineering measures shield the roadbeds, embankments or both of them from solar heating and cool them by convection to maintain a shallow thaw depth, which thus protects the permafrost. The spaces between rocks are the key to increasing cooling energy and heat exchange under the riprap.

The ripped-stone embankment was constructed as follows (Fig. 7(a)). A 1.2m high layer of coarse stones with diameter of 40-50cm was laid on ground. The layer stretches out of roadbed 5m long at the south slope and 3m long at the north slope respectively. With this method, the cold energy through the ripped-stone layer, which transfers into the underground soil, is 2-4 times of what it is in the common roadbed without any engineering methods. The ripped-stone protecting slope roadbed was constructed with coarse stones laid on both sides of roadbed (Fig. 7(b)). There are two kinds of diameters, 10-15cm and 40-50cm, applied in this method. Both of them are respectively 1.4m thick at the south slope and 0.4m thick at the north slope. The U-shaped combination roadbed is a kind of roadbed, which combines the ripped-stone embankment and ripped-stone protecting slope roadbed (Fig. 7(c)).

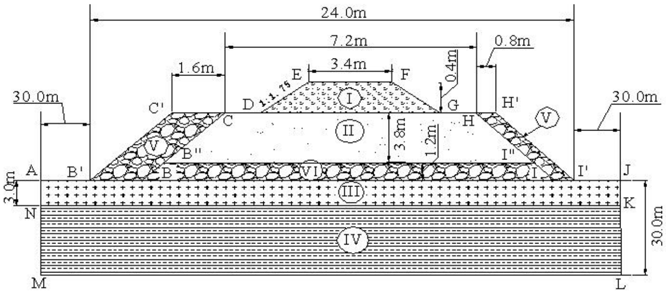
(2) Heat Pipe Roadbed: Heat pipes stabilize permafrost by removing heat from permafrost and dissipating it into the ambient cold air. They employ evaporative cooling to transfer thermal energy from one point to another by evaporation and condensation of a coolant. The temperature of permafrost ground decreases when the lower vaporizing section in the



(a) Ripped-stone embankmen.t



(b) ripped-stone protecting slope roadbed.



(c) U-shaped combination roadbed.

Fig. 7. Three kinds of riprap roadbeds applied in QTR.

permafrost absorbs warm energy, while the materials turn into gas from liquid. Thus the work of heat pipes rely on a temperature difference between the upper part and lower part of the pipe. The heat pipes were designed 9m long, with 7m long inserted into ground and 3m interval between every two pipes (Fig. 8).

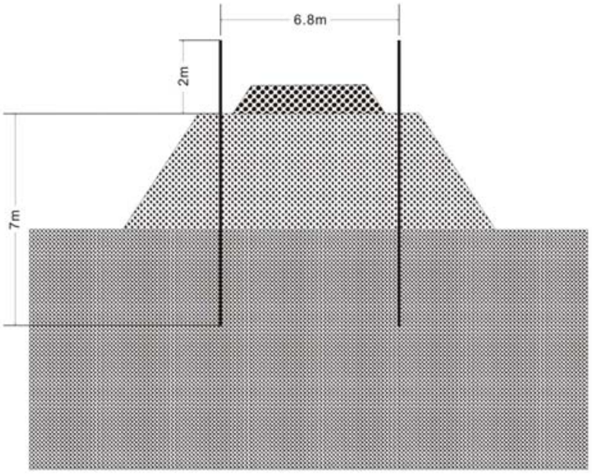


Fig. 8. The heat pipe roadbed.

(3) Bridge on land (Bridge Instead of Roadbed): If the annual average earth temperature of the permafrost is very high (0~-0.5℃), it's not sufficient for protecting permafrost under the embankment. To minimize the thermal disturbance caused by construction, we adopted bridges instead of roadbeds to across over the permafrost land. The Qingshui river bridge is such a longest one along QTR (Fig. 3). The depths of piles supporting the bridge are between 25m and 30m, and the girders are 8m long.

(4) Ventilated-pipe Roadbed: The ventilated-pipe roadbed has an open pipe installed beneath the roadbed through the embankment that cools the ground. In cold seasons, because the density of cold air is greater than that of the warm air in the vent-pipe, the warm air could be extruded by the effect of self-weight and wind and the warm energy around the pipe could be taken away as well. All the accumulation of heat can be carried away through the pipes with a diameter of 40cm (Fig. 6). Thus the permafrost may be maintained in frozen state.

(5) Awning Roadbed: Because of the strong solar radiation on QTP, awning roadbed is constructed to shade the roadbeds and embankments from solar heating. This kind of embankment can reduce the radiation to the surface and slope of the roadbed. It can also prevent rain from entering into embankment and snow from covering the surface. There are two kinds of awning roadbed, one covers over tracks and the other covers on slope of roadbed (Fig. 9).

Testing Sections. As the beginning of the design phase, some kinds of special roadbed structures and engineering methods, such as the insulation material embankment (as dominant measure), the riprap roadbed, ventilated-pipe roadbed, and thermopile embankment etc, were adopted to keep the embankment deformation within an acceptable range in the aspect of temperature variation. In order to verify the initial design idea and the chosen measures applicability, four experimental sections were regarded as pioneer engineering had been conducted before construction in 2001. The field test sections consist of three roadbed engineering sections and two tunnel engineering sections, which are, the very-warm-fine-particle test engineering project along Qingshui river, the thick ground ice test engineering project along Beilu river, the thawing area and permafrost zone transition section test engineering project along Tuotuo river, and the permafrost tunnel test engineering projects on Kunlun mountains and Fenghuo mountains, respectively. The settlement and deformation of the embankment, the stress and deformation of these structures, as well as air temperature and meteorological observation were carried out. At the same time, the laboratory tests were performed as well.

In Situ Observation. The deformation of the permafrost is a relatively long-term and slow process, which is further complicated by the fluctuations in ground temperatures. Therefore, the monitoring of ground temperatures and deformation are quite important during the construction and operations of QTR. The temperature profiles, the permafrost table and the variations of mean annual ground temperatures can be obtained from inspecting the soil temperatures, which directly reflect the thermal regimes of roadbed. The frost heave and thaw collapse are unique phenomena influencing the stability of the permafrost roadbed in permafrost zone, which are directly reflected by the deformation.

(1) Temperature Monitoring: Considering the distribution of the geomorphic unit along QTR, the sub-zone of the mean annual ground temperature in the permafrost region and the setting principle of the different engineering measures, the system including 6 temperature monitoring holes is set at every transect, of which, one is in the centerline of the railway embankment, two at each side of the railway shoulder (3~3.5m away from the centerline), and the others at each slope foot and at the natural ground, about 20m away from the slope foot line respectively. The temperature monitoring holes should extend to a depth about 5~10m below the natural permafrost table (Fig.10). In the typical measurement sections, the measurements also include the parameters in meteorology, such as air temperatures, wind velocity, wind direction, solar radiation, precipitation and evaporation.

(2) Deformation Monitoring: Taking the post-constructing deformation of settlement and the active layer thawing deformation into consideration, there should be set 6 spots for deformation monitoring at each transect, of which, three are on the roadbed surface (one at the centerline and two at each shoulder), and the other three are set below the roadbed (originally natural surface), which are located directly blow the former three sites (Fig.10.).

Fig.9. Two kinds of roadbeds.

In order to investigate the deformation under the influence of the frost heave and thaw settlement, the monitoring system has been constructed since 2001, which includes the deformation monitors distributing in 6 spots at each transect every 100m along the 546.41Km of permafrost regions, and the temperature monitors distributing in 100 monitoring sections with 6 temperature monitoring holes at each transect. The degradations are measured every 15 days manually; however, the temperature data are collected automatically every 1 hour and transferred wirelessly from the field to the lab in Golmud. The data collection covers a wide range of major geomorphic units such as Kunlun mountainous region, Chumare River plain, Kekexili mountainous region, Fenghuo Mountains and Wuli mountainous region, Tuotuo river basin and Yanshi plain. These regions include the very warm and very unstable permafrost zone (section I: -0.5□ < Ta < 0), the warm and unstable permafrost zone (section II: -1□ < Ta < -0.5□), the lower temperature and almost stable permafrost zone (section III: -2□ < Ta < -1□), and the low temperature and stable permafrost zone (section IV: Ta < -2□). The temperature observation points were distributed mainly at section I, section II and section III. The profiles also covered different engineering structures in permafrost region.

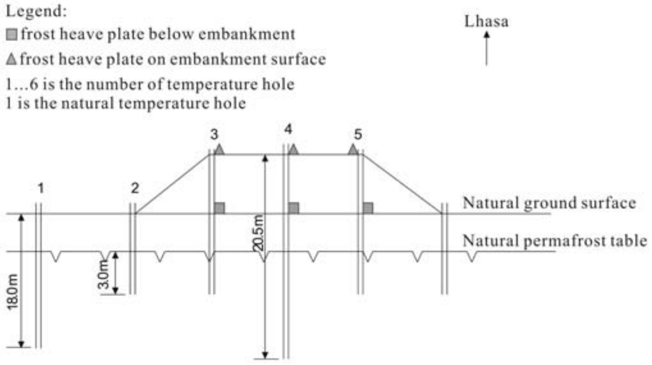


Fig. 10. A typical distribution of monitoring transect for temperatures and deformation (by prof. Ma Wei).

Deformation of Embankments. The deformation of embankments at typical segments in the permafrost regions of QTR is shown in Table 1. The active engineering measures have been applied at these regions, and the embankments were begun to construct in 2001, and were completed in 2002.

Table 1. The deformation at different permafrost embankments along QTR

Region	Annual Air temperature/℃	Ground Temperature of Permafrost/℃	Table of permafrost at natural sites/m	Deformation in the first year/cm	Deformation of the second year/cm	Deformation of the third year/cm	Deformation in 2005/cm	Deformation in 2006/cm
Chumaer Plateau	-4.2	-0.2~-1.5℃	2~4	21~24	10~12	2~4	0.5-0.8	0.2-0.6
Tuotuo River Basin	0.2	-0.0~-1.0℃	2.5~4.5	24~26	11~13	3~5	1	0.5
Tongtian River Basin	-3.0~-3.8	-0.0~-0.7℃	3~4	27~30	12~14	4~6	1-1.6	0.3-0.7
Wudaoliang	-5.6	-0.5~-1.5℃	1.2~2	5~7	3~4	1	0.4-0.7	0.2-0.4
Kunlun Mountain	-5.6~-5.8	-1.0~-2.0℃	1.3~1.8	3~5	2	1	0.2-0.5	0.1-0.2
Beilu River	-3.8~-4.2	-0.7~-1.5℃	1.5~2.0	8~11	5~7	2	0.3-0.7	0.1-0.3

In the first year when the embankments were completed, the deformations were monitored. Because of the influences of thermal energy brought by railway construction and global climate warming, the first year's deformations were serious. Especially at the regions of Tuotuohe Basin and Tongtianhe Basin, where belong to the warm and unstable regions, section I and section II, the ground temperatures are higher than -1.0℃, the deformations were greater than 20cm. In 2003 when the embankments had been completed for more than 1 year, the thermal energy had been reduced rapidly, and the deformations decreased. At the low-temperature and stable regions, where the ground temperature of permafrost is about -1.0~-2.0℃, section III, the deformation was lower than 10cm. In 2004 when the ground temperature became stable, the deformations decreased remarkably, and after 2005, the deformations have become stable, which were lower than 1cm. When QTR were put into test operation in 2006, the deformations have been satisfied by the operation.

Ground Temperature of Embankments. Based on the local observatory data of air temperature decreasing period of Beilu River testing segment of QTR in 2002 and 2003, the ground temperatures of the riprap roadbeds were monitored and analyzed. The embankments were completed in June, 2002. As temperatures shown in Fig.11 and Fig.12, after October, 2002, when ground temperatures were firstly monitored, temperatures in layers between ground surface to 2m underground in the centre boreholes of the riprap roadbeds were lower than that in natural boreholes, 20m away the embankment. The temperatures became lower and lower and got to that of the natural borehole in layers lower than 2m after 2003. It showed that the riprap roadbed had some effects on protecting the permafrost embankment.

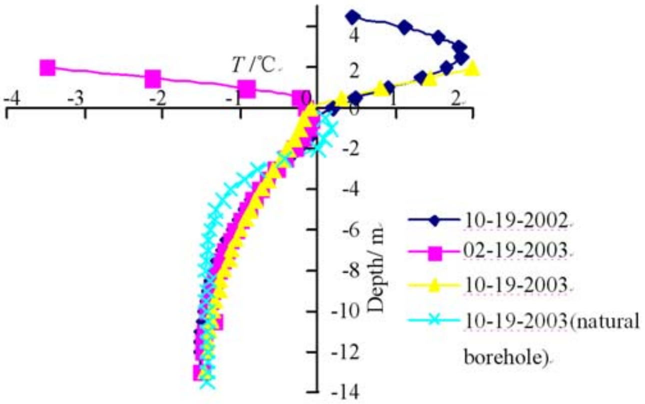


Fig.11. Ground temperature change of center bore at the riprap roadbed embankment (the grain size between 5 to 8 cm).

Brief Summary. Based on laboratory and field tests, the insulation material embankment is proved to be a passive protecting permafrost measure and it is not effective for protecting permafrost from deformation at the warm permafrost region, which belongs to section I and section II (Sheng, 2003). However, the other measures can cool ground temperature and protect permafrost from deformation effectively (Ma, 2002; Niu, 2003; Lai, 2003; Wu, 2005; Ma, 2005).

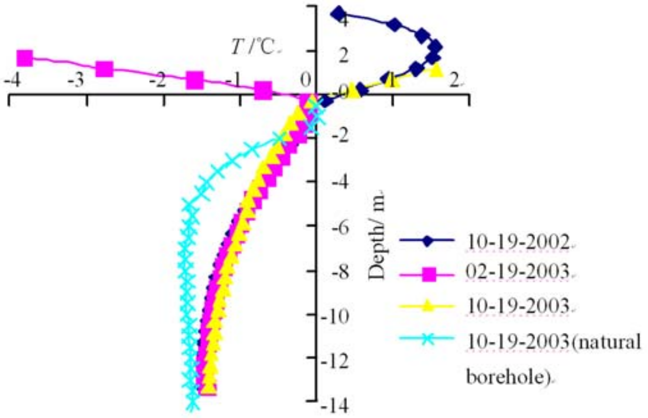


Fig.12. Ground temperature change of center borehole at the riprap roadbed (the grain size between 40 to 50 cm).

In the second design phase, the active measures protecting permafrost were adopted, such as the riprap roadbed, heat pipe roadbed and dry bridge. And these applied engineering measures proved to be capable of diminishing deformation of roadbed and decreasing ground temperature of the permafrost along QTR. So, these active engineering measures can be used to keep the stability of the embankment in the permafrost.

Chinese scientists have gained better understanding of permafrost and developed new techniques to stabilize railway embankment on permafrost through observations and studies since 1960's. These knowledge and techniques make it successful to construct the QTR.

The speed of the train and the damage ratio are two major criteria for evaluating the railroad in permafrost areas. At present, the speed of trains running on the QTR is around 120km/h and 100km/h through unfrozen soil areas and permafrost regions respectively, which is the highest speed in permafrost regions in the world. The damage ratio is only less than 1% by the end of 2006.

Lack of Oxygen

At 4,500m elevation in the Tibetan Plateau, with the atmospheric pressure and oxygen 45% lower than at sea level, an annual average air temperature of -5℃, and extremes including the lowest temperature of -47.8℃ and wind speeds higher than 30m/s. Add in solar and ultraviolet radiation 1.5 to 2.5 times what it is at sea level, and not only is preconstruction research and fieldwork a challenge, but so is the construction itself.

During the period of construction for QTR, the three-class hospital system was set up. There were total 115 hospitals and more than 600 doctors and nurses working on the Tibetan Plateau, and 17 oxygen producing stations and 25 hyperbaric oxygen chambers were equipped for the constructors along QTR. As a result of successful operating of the health care system, the sick constructors could get effective treatment in 30 minutes, that the success ratio of emergency treatment for the acute altitude disease, such as hydrocephalus and pulmonary edema, was 100%, and there was nobody died for altitude disease when constructing for QTR.

The Tibetan Plateau has a unique and fragile ecosystem. During the period of designing for QTR, the route of the railway was designed to avoid nature protection area as far as possible.

In order to protect the wild animals, 33 animal underpasses were constructed along QTR. Additionally, to minimize environmental disturbance during construction, staging areas were planned to minimize surface disturbance and avoid sensitive areas, and were revegetated at the completion of the construction. (Fig.13)

Fig. 13. Staging area (left) and animal path (right, from Xinhua Press).

Environmental Frangibility

In order to protect the environment during the life of the railway's operation, the trains are designed as a sealed system to protect the environment it passes through. The train cars are completely sealed, so no waste, litter or discharges are thrown out from the cars. All refuse is contained on board the train for disposal at the stations.

The fund put into the project of environmental protection is about 150 million US dollars, and the environmental protection supervision was firstly operated during construction of QTR.

EARTHQUAKE DAMAGE MITIGATION

The Tibetan Plateau is one of the most tectonically active areas of the world and also one of the most seismically active regions, where strong earthquakes occurred frequently. There are 33 Ms6.0-6.9 earthquakes and 3 Ms7.0-8.5 earthquakes occurring in the QTP between Jan.1, 1980 to Jul.31, 2006 (Fig.14).

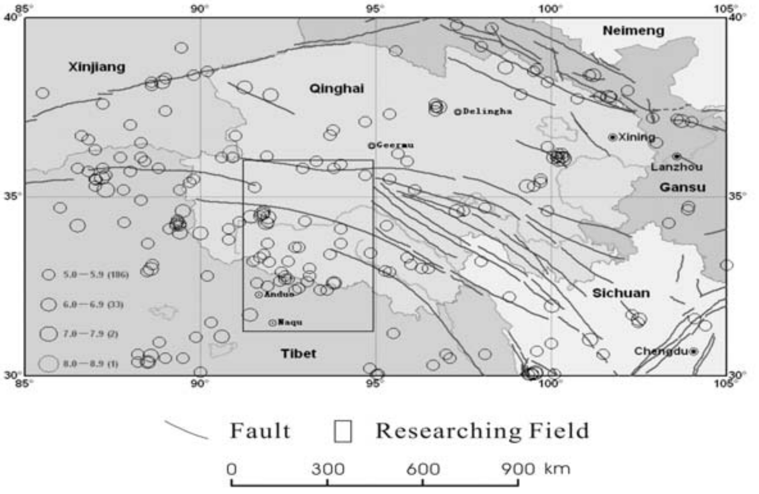


Fig. 14. Distribution of epicenters at and around the Qinghai-Tibet Plateau between Jan. 1, 1980 and Jul. 31, 2006.

Especially, the west of Kunlun Mountain pass Ms 8.1 earthquake, which caused a surface rupture 426km long in the permafrost regions, on November 14, 2001, induced a certain extent of damage and potential hazard to the infrastructure and construction projects on the Qinghai-Tibet Plateau which relates to the strategy of the developing western China, such as the QTR and the Qinghai-Tibet Highway (Fig.15).

Fig. 15. A train was running across the rupture belt caused by the 8.1 earthquake in 2001.

Faced with the problem of how to construct a safe railway on the Tibetan Plateau, the construction of the railway has been paid much attention to earthquakes and active faults. The railway traverses the active faults at several places, which were the main boundaries of active plates and large earthquakes took place there. Therefore, it is very important and pressing for both construction and operation of the railway to study earthquake damage mitigation along the Qinghai-Tibetan railway.

Identification of Active Faults and Seismic Zonation at the Key Sections along QTR

For the entrustment of China Railway First Survey and Design Institute, we a group of experts from some institutes of CEA including Lanzhou Institute of Seismology undertook the project of "Identification of active faults and seismic zonation at the key sections along the QTR" from 2000 to 2002. The work zone was divided into two classes, normal section and key section. There are two key sections along the railway, which are the South Mt. Pass-Kunlun section and Dangxiong-Yangbajin section. The South Mt. Pass-Kunlun Mt. section is about 130km long, which includes three large size active faults, namely, the Middle Kunlun Mt. Fault, where a earthquake of magnitude 6.9 occurred in 1902, the East Kunlun Mt. Fault, where a earthquake of magnitude 7.5 occurred in 1937, and the Kunlun Mt. Pass Fault, where a earthquake of magnitude 8.1 occurred in 2001. The Dangxiong-Yangbajing section is about 180 km long, including the Bengco Fault, where an earthquake of magnitude 8 occurred in 1951, the East Nianqingtanggula Mt. Fault, where an earthquake of magnitude 7.5 occurred at Dangxiong in 1952, and an earthquake of magnitude 8 occurred at the north of Dangxiong in 1411. Faults of these key sections are more active than other sections along QTR, since the sections, Kunlun Mt. Pass to Sangxiong and Yangbajing to Lhasa along the railway, belong to normal sections. The field investigation and research shown that there are many active faults in the QTR region, which may cause moderate or strong earthquakes, such as the active faults from Kunlun Mt. Pass to Tanggula Mt. Pass, the north of Anduo to Naqu, and so on.

The harsh climate on the Tibetan Plateau is a challenge to investigate those active faults. However, in a limited preparing time of QTR Project, geologists took proper methods to get the following major achievements: (1) The report on faults activity and seismic zoning of key sections along QTR; (2) The map (1:250,000) of active faults, which covers 25km wide in both sides of the railway; (3) The map (1:250,000) of seismic intensity zoning at the key sections, which covers 25km wide in both sides of the railway; (4) The map (1:1,000,000) of seismic zonation at the common sections, which covers 25km wide in both sides of the railway; (5) The report of evaluation for activity of major faults locating at the sections of Kunlun Mt. Pass-Sangxiong and Yangbajing-Lhasa along the railway.

The results shown that there are 44 actives faults identified at the sections of Kunlun Mt. Pass-Sangxiong and Yangbajing-Lhasa, which has a length of 790km and a width of 50km along the railway. Among them, 24 recent active faults were assessed as the Holocene Epoch crossing QTR, in which 18 active faults could move and dislocate in the future 100 years. During designing and constructing QTR, the appropriate engineering measures should be taken at these sites, where the 18 Holocene Epoch active faults cross the railway. The Wenquan Fault, the Sangxiong section and the Yangbajing section of the east Niantanggula Mt. Fault, are all the Holocene Epoch active ruptures, which are parallel with close to the railway. The railway should depart from these two faults as far as possible.

Seismic intensity zoning map is shown as Fig.16 with the exceedance probabilities of 10% in 50 years for seismic design of the QTR project. The proportion of length for each intensity zone is given in table 2. The largest intensity along the railway exceeds □ degree, and the smallest is □ degree.

Compared with "China Seismic Intensity Zoning Map (1990)", it shows that a higher seismic intensity region extends along the QTR. Northern boundary of □ zone, which locates at the north of Budongquan, enlarges about 20 km northwards. However, the southern boundary retracts about 10km northwards. The section, from Wudaoliang to Sidaoban, belonged to □ zone, but it is □ in the new zonation map.

Northern boundary of □ zone in the section, Dangxiong-Yangbajing, enlarges about 80km northwards. The □ zone nearby reduces accordingly, and its northern boundary moves to south about 20 km.

Fig. 16. Seismic intensity zonation for QTR (1:1,000,000).

Table 2. Proportions of QTR in the seismic intensity zonation

Intensity zonation	Ⅶ	Ⅷ	≥Ⅸ
Accumulative length (km)	612	365	141
Proportion of length (%)	54.8	32.6	12.6

Seismic Safety Assessment of Large Bridges

Seismic safety assessments for four significant bridges sites of QTR were carried out. This work plays an important role for assessing the stability of four grand bridges in QTR, which are Dunlang grand bridge, Jiuzila grand bridge, Dangquhe grand bridge, and Langbuqu grand bridge respectively from north to south. The objective of this assessment effort was to offer seismic parameters for design, by which the bridges would have an enough capability to withstand a strong earthquake.

In seismic safety assessments of the four sites, the analysis on seism-geological features and assessment of seismic activity in regional and near fields, attenuation relations of ground motion, seismic risk analysis, and in-situ test related to velocity of shear wave were involved. And finally the parameters of design ground motion and seismic intensities with the exceedance probabilities of 63.5%, 10% and 2% in 50 years at the four bridges' sites as well as velocity of shear wave in permafrost deposits along TQR are respectively provided in Table 3 and Table 4.

Table 3. Parameters of horizontal component of PGA and its response spectrum (damping ratio of 5%) for design at site of Dunlang great bridge

Exceedance probabilities in 50 years	A_{max} (gal)	T_1 (sec)	T_2 sec)	β_m	α
10%	450	0.18	0.50	2.70	1.0
5%	600	0.18	0.55	2.70	1.0
1%	990	0.20	0.80	2.75	1.1

Table 4. Observation results of wave velocity in boreholes along QTR

Lithology	Depth (m)	Velocity (m/s)		
		Soil	Vp	Vs
silty clay	0-4	unfrozen soil	230-368	150-242
		frozen soil	305-590	206-420
	4-10	frozen soil	564-1050	395-740
	10-15		1026-1368	780-943
mudstone	0-4	unfrozen soil	330-541	216-328
		frozen soil	395-730	296-532
	4-10	frozen soil	770-1350	545-869
	10-15		1489-1620	910-1043
marl	0-4	unfrozen soil	812-904	526-644
		frozen soil	1020-1332	750-890
	4-10	frozen soil	1377-1592	878-1050
	10-15		1579-1653	1121-1184
fine sandy soil	0-4	unfrozen soil	189-367	120-263
		frozen soil	278-562	204-400
	4-10	frozen soil	382-643	251-456
	10-15		632-765	465-550

CONCLUSIONS

(1) Successful construction of QTR is a remarkable feat in railway construction history of permafrost region, which makes all the provincial capital cities of China to be connected by railways. It would benefit all ethnic groups in both Qinghai province and Tibet Autonomous Region of China, where economic growth and social development will be speed up.

(2) All the engineering and management measures to solve three major problems, permafrost, lack of oxygen and environmental protection, have been proved to be efficiency and practical, which may be used for reference of the other railway construction projects in high elevation and permafrost areas.

(3) The research achievements in the seismic safety evaluation, including seismic hazards analysis, seismic intensity zonation and investigation of active faults, have been applied into the design, construction, and maintenance of Qinghai-Tibet Railway, which have partly examined by the West Kunlun Mountain Pass 8.1 Earthquake in 2001 in both seismic intensity and influence of active faults and will continue to show its effects on seismic safety of the railway operation.

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