

## A STUDY ON CHARACTERISTICS OF GROUND MOTION IN PERMAFROST SITES ALONG THE QINGHAI-TIBET RAILWAY

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### ABSTRACT :

Based on field geological investigation at permafrost regions, geological description and test of waves velocities of the 14 typical drilling holes distributing permafrost areas along the Qinghai-Tibet railway, elementary characteristics of soil wave velocities at the permafrost regions are presented. And then, combining results of dynamic triaxiality test, using 3 time histories of ground motion acceleration with the exceedance probabilities (62.5%, 10% and 2%) related to this research area, characteristics of ground motion are analyzed for the 10 permafrost profiles by an equivalent linearization method to estimate the seismic response of frozen soil ground. Moreover, influence of earth temperature on seismic acceleration respond spectrum for permafrost sites is studied. Consequently, there are 4 results could be revealed as follows: 1) at the similar conditions, waves velocities of frozen soils along the Qinghai-Tibet railway are greater than other non-frozen soils areas, and velocity ratio between shear wave and compression wave does the same also; 2) earthquake strength is a critical factor to influence the acceleration amplitude of ground motion at permafrost regions, e.g. with the depressing of earthquake strength, acceleration amplitude of ground motion reduces gradually; 3) proportions of moderate and short period of seismic acceleration respond spectrum in permafrost regions are evidently greater than other non-frozen areas; and 4) amplitude of acceleration response spectrum of ground motion decreases distinctly while earth temperature of frozen soils reduces. As an expectation of authors, this paper should contribute to earthquake disaster prevention of the engineering structures in permafrost areas at Qinghai-Tibet Plateau.

### KEYWORDS:

Qinghai-Tibet railway, permafrost, velocity of wave, ground motion, earth temperature

### 1. INTRODUCTION

The Qinghai-Tibet Plateau (QTP) is one of the most tectonically active areas of the world and also one of the most seismically active regions, a total of 33 Ms 6.0-6.9 earthquakes and 3 Ms 7.0-8.5 earthquakes have occurred since 1980 (Fig. 1). The west of Kunlun Mountain pass Ms 8.1 earthquake on November 14, 2001 produced a large scale ground failure in the permafrost regions, and damage to the infrastructure and construction projects in the permafrost regions in the QTP and so impacted the strategy for developing western China.

The Qinghai-Tibet railway (QTR) is 1142km long from Golmud to Lhasa, and it passes through 546.41 Km of permafrost regions. It was put into test operation on July 1<sup>th</sup>, 2006. Earthquakes can influence the stability of the infrastructure and construction, in the QTP such as the QTR. Therefore, it is very important and pressing to study earthquake disaster mitigation and prevention in the permafrost regions in the QTP.

The area of permafrost in China is around 10% of the total permafrost area of the world and about 21.5% of the whole area of the Chinese continent. However, the area of permafrost with high elevation in China is the largest in the world. The QTP is a region of permafrost with the largest area, the biggest depth, and the lowest temperature in the region with moderate and low altitude, in the north hemisphere.

The permafrost is a very special soil, and it is quite sensitive to temperature changes, as physical, chemical, and engineering features are inherently unstable and correlated with temperature. Moreover, these characteristics are

also influenced by the ice content, which is directly correlated to temperature and decreases with the rise of temperature (Xu Xuezu, et al, 2001, Zhang Luxin, 2000).

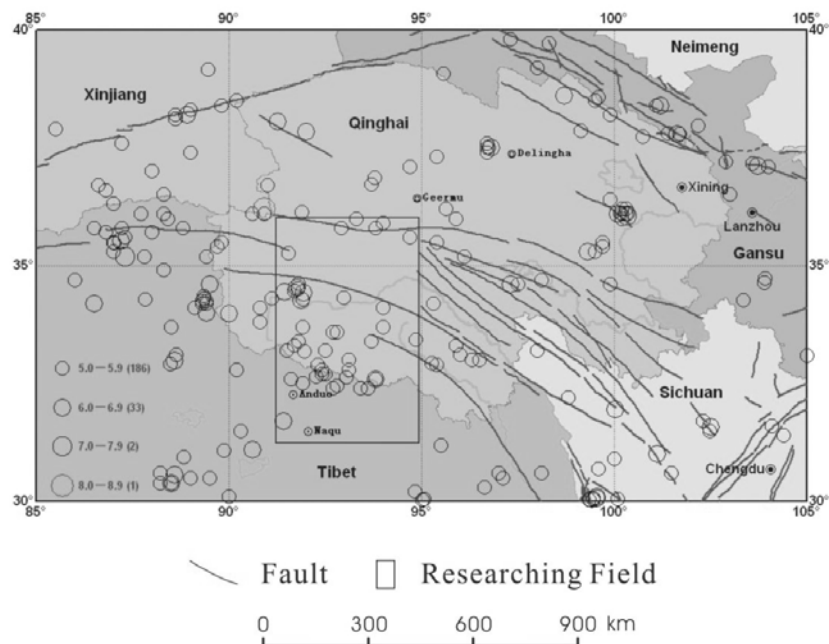


Fig. 1 Epicenters at and around the Qinghai-Tibet Plateau between Jan. 1 1980 and Jul. 31 2006

Variation in temperature is one of the most important factors that influence the mechanical properties of permafrost and also the one that affects the bearing capacity of foundations in permafrost areas. However, because of global climate change, the average air temperature on the QTP has increased by 0.2-0.4°C per year. The temperature increase is more predominant in winter and the annual range of air temperature is decreasing gradually. Furthermore, the air temperature on the plateau is predicted to increase by 2.2-2.6°C in the next ten years. Thus, the degradation of permafrost appears regionally (Wang Shaoling, 1996), and consequently the natural geography, geological environment, and engineering geological environment of permafrost area along the QTR will change greatly (Wang Guoshang, et al, 1996).

The influence of permafrost degradation on anti-seismic performance of the permafrost sites includes two aspects: (1) the deformation of permafrost under seismic loading usually becomes much greater and fails more easily, and (2) the influence of the changes in dynamic characteristics of permafrost on ground motion parameters at a site can be significant (Wu Zhijian, et al, 2003). Therefore it is important to study the characteristics of ground motion and the influence of ground temperature on the parameters of ground motion at permafrost sites. Ground motions in typical segments of the permafrost areas along the QTR were studied to provide input for seismic hazard assessments and hazard mitigation from July of 2004 to June of 2005.

## 2. SOIL VELOCITIES AT PERMAFROST SITES ALONG THE QTR

The studied permafrost regions are between DK1004+000~DK1509+500, which generally covers the permafrost areas along the QTR (Fig. 2).

The velocity data are important parameters for calculating soil response. For this project, the soil velocity data at typical permafrost sites were acquired using the FDP204PDA portable motion instrument and borehole three-dimension accelerometers. There are two main parts of the profile of permafrost, i.e. the upper part is active layer and the lower permanent frozen layers. The depths of active layers are currently between 1m and 4m at permafrost regions along the QTR. The freezing and thawing of active layers are greatly influenced by the

seasonal variation in air temperature, and the lower layers always remain frozen and are less affected by air temperature. A statistical comparison has been done between velocities of four typical soils, i.e. silty clay, mudstone, marl, and fine sandy soil at the 14 boreholes (Tab. 1).

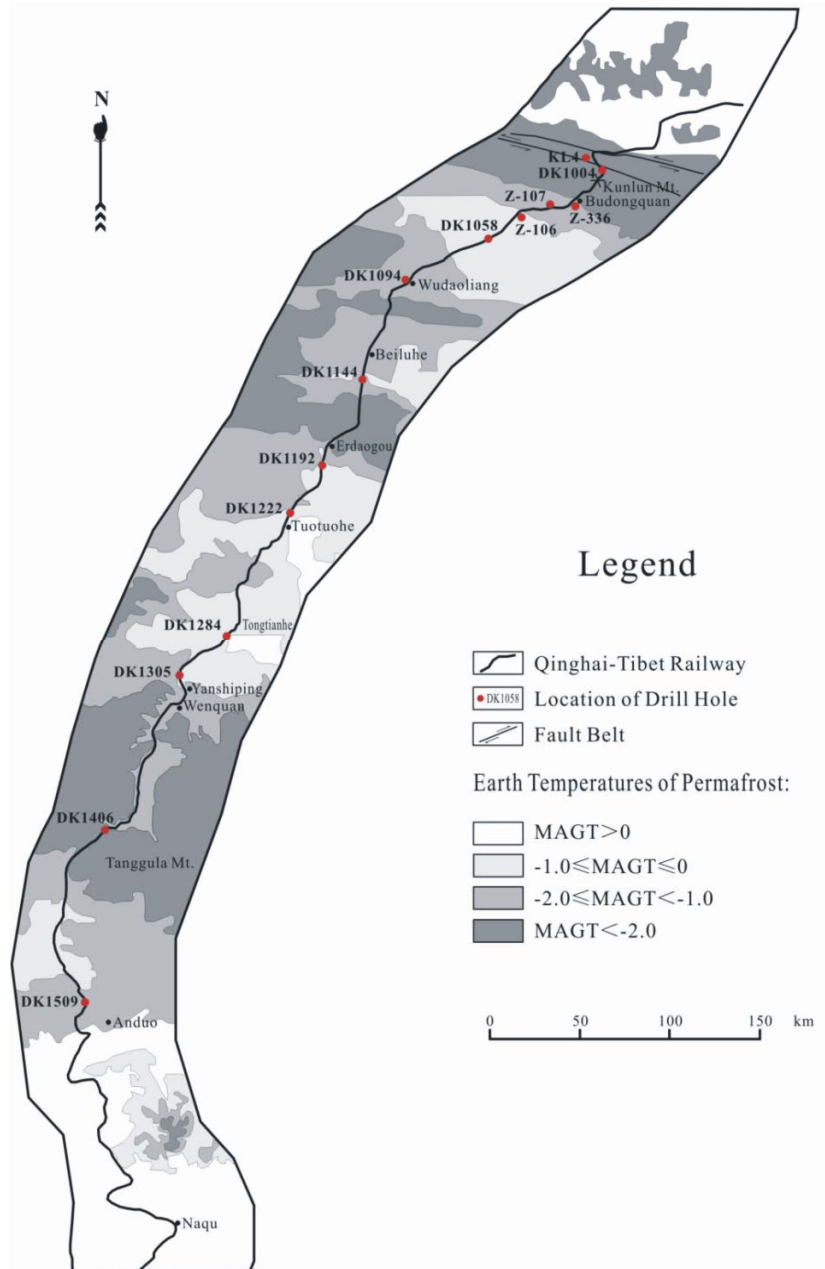


Fig. 2 Distributions of earth temperature and drill holes along the Qinghai-Tibet Railway

1. The ratio of S-wave velocity to P-wave velocity, in permafrost areas along the QTR is around 0.7, which is greater than the ratios of other non-permafrost regions.
2. As indicated from Tab. 1, velocities at the different locations vary not only with the lithologies but also with ground temperature and ice content. Statistical ratios of velocities between frozen soils and non-frozen soils are about 1.2-1.6 and 1.4-1.7 for S-wave and P-wave, respectively. This means that soils with lower temperature have higher velocities.

Tab. 1 Field testing results of wave velocities in boreholes along the Qinghai-Tibet railway  
 (data acquired in summer, 2004)

Lithology	Depth (m)	Velocity (m/s)		
		Soil	V <sub>p</sub>	V <sub>s</sub>
silty clay	0-4	unfrozen soil	230--368	150--242
		frozen soil	305--590	206--420
	4-10	frozen soil	564--1050	395--740
			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
			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
			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
			632--765	465--550

### 3. INPUT SEISMIC MOTIONS AND CLASSIFICATION OF THE PERMAFROST LAYERS

#### 3.1. Input seismic motions

Artificial seismic waves with exceedance probabilities of 63%, 10% and 2% respectively in 50 years, developed by Xiaojun Li, Professor of Chinese Earthquake Administration (Fig. 3), were used as input seismic motions and were inputted at 15m depth, the depth to stable temperature. The shear moduli, damping ratios, and shear wave velocities (Wang Lanmin, et al, 2005), were determined by dynamic triaxial tests conducted by the State Key Laboratory of Frozen Soil Engineering, Chinese Academy Sciences and by field tests at the permafrost sites along the QTR.

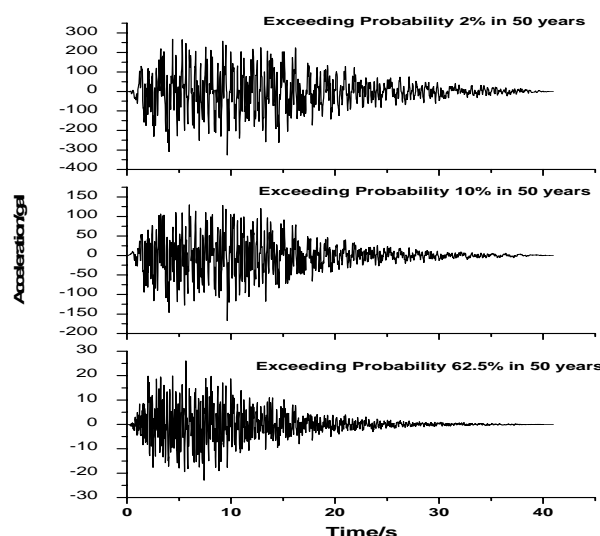


Fig. 3 Input seismic motions, provided by Pro. Xiaojun Li

### 3.2. The classification of permafrost layers

The typical profiles were classified according to the field data of boreholes. The depths of active layers, which are also the tables of permafrost, are dependent on altitude, geological condition, ground vegetation cover, etc. The ground temperature changes significantly with air temperature variation to a depth of 4m. The ground temperatures are currently between  $-1 \sim -3^{\circ}\text{C}$  from 4m to 15m, and are basically stable below 15m at the studied sites. In general, the ground temperature of permafrost between the bottom of the active layer and 10 m underneath vary much more than the temperatures between 10m and 15m underground. The temperature difference between the lower permanently frozen soil layers at the south slopes and the north slopes can be greater than  $2^{\circ}\text{C}$ . The depth where permafrost can be found for the north slope is only about 1m but that for the south slope is much deeper (Wu Zhijian, et al, 2003).

The classification of the permafrost profiles is based on the results of the field investigation, site exploration and testing, and laboratory tests for water content, unit weight etc. The physical parameters of profile at DK1144+000 for analysis are listed in Tab. 2.

Tab. 2 Parameters of physical property at borehole of DK1144+000  
(data acquired at the field on Aug. 9, 2004)

Soil	Ice Content	Temperature	Depth	Thickness	Density	Vs
	(%)	$^{\circ}\text{C}$	(m)	(m)	( $10^3\text{kg/m}^3$ )	(m/s)
loamy soil	0	0.30	1.80	1.80	2.28	172
fine sand	0	-0.41	2.20	0.40	0.99	194
ice layer with soil	>50	-1.25	3.30	1.10	1.16	370
ice layer with soil	>50	-1.44	4.00	0.70	1.63	387
silt	45	-1.52	4.70	0.70	1.89	530
silt with fine sand	15-20	-1.60	6.00	1.30	2.34	529
clay with silt	30	-1.56	7.50	1.50	1.96	543
clay	<20	-1.49	9.00	1.50	2.00	558
claystone, intense weathering	<25	-1.45	10.50	1.50	2.35	509
siltstone with claystone, intense weathering	10-20	-1.43	12.00	1.50	2.11	760
claystone with siltstone, intense weathering	10-20	-1.42	13.00	1.00	2.29	766
claystone, intense weathering	10	-1.38	15.20	2.20	2.14	754
claystone, intense weathering	<10	-1.38	18.00	2.80	2.14	822

## 4. RESULTS OF RESPONSE ANALYSIS

### 4.1. Characteristics of peak acceleration and duration

The acceleration time histories of the 10 boreholes under seismic ground motion with different exceedance probabilities within 50 years were shown in Fig. 4. The envelope curve of time history for 63% probability of exceedance is approximately linearity best but the 2% exceedance shows distinct non-linearity because of long duration of relatively great acceleration.

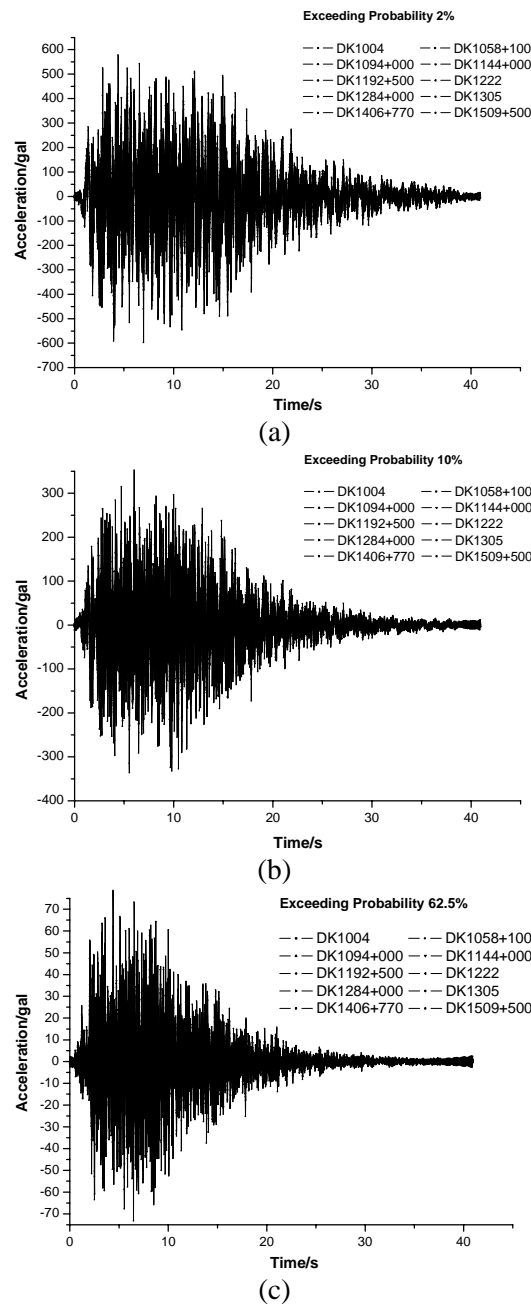


Fig. 4 Variations of acceleration under seismic ground motion with three exceedance probabilities of 63.5%, 10% and 2% in 50 years

It is also illustrated that the sites amplification coefficients are 2.7, 3.2 and 4.3 respectively with probabilities of exceedance from 2% to 63%. The coefficients reduce along with the increasing of seismic intensity due to the influences of nonlinearity.

#### 4.2. Characteristics of response spectra for acceleration

It is indicated schematically in Fig. 5 that the amplitude of the response spectra for acceleration under 2% probability of exceedance is the largest, and the components are more abundant at the moderate and long periods. The amplitudes of spectral acceleration are different at each of the 10 borehole profiles, reflecting the different

site characteristics, such as physical characteristics, ice contents, and ground temperatures, etc.

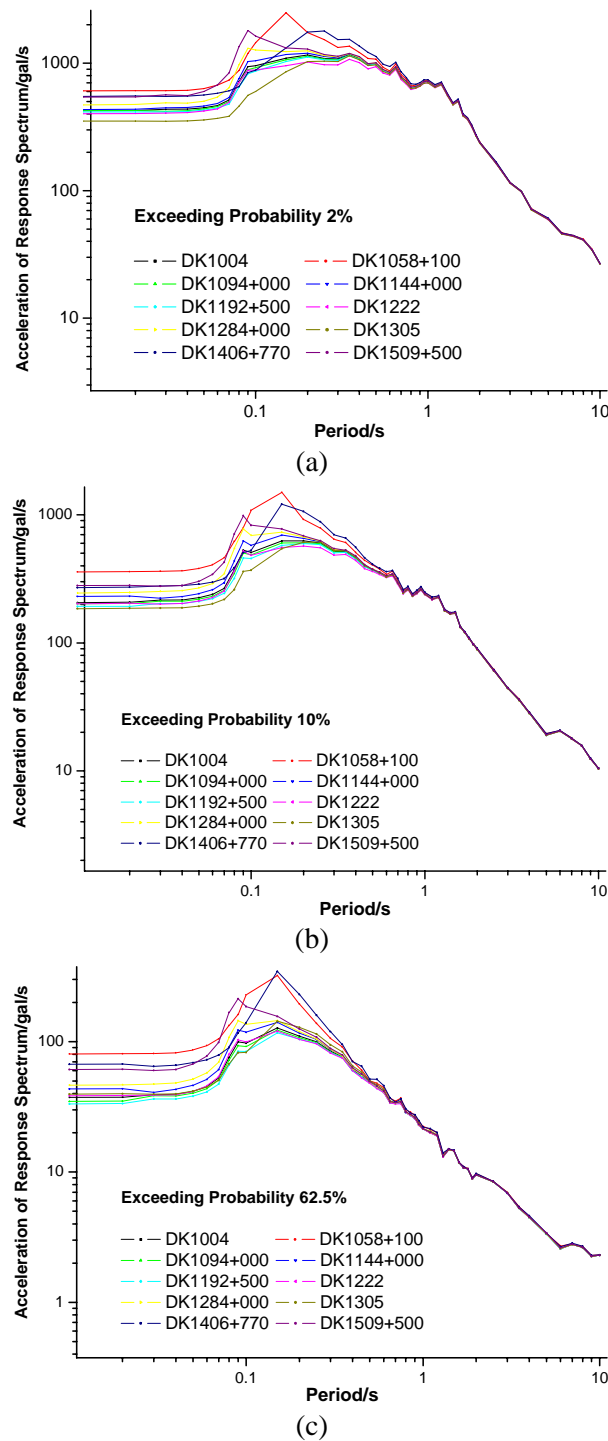


Fig. 5 Acceleration spectrums under seismic ground motion with three exceedance probabilities of 63.5%, 10% and 2% in 50 years.

Compared with the spectral accelerations for some non-permafrost areas, typical spectral accelerations for the permafrost areas have much more abundant in components at moderate and short periods and peak accelerations and characteristic periods are less. In addition, the amplitudes of spectral acceleration decrease much more quickly than the ones of non-permafrost areas after the characteristic period, however, the increasing segments

of permafrost regions rise more rapidly.

## 5. CONCLUSIONS

(1) Ground temperature and ice content are important factors to influence the velocities of permafrost. The lower the temperature the higher the velocity, the larger the ice contents the higher the velocity.

(2) Spectral accelerations at the permafrost sites along the QTR have much more abundant in components at moderate and short periods than that of the non-permafrost sites, and peak accelerations and characteristic periods are less.

(3) Ground temperature influences parameters of ground motion at the permafrost sites remarkably. Displacement, velocity and fundamental period decrease with decrease in ground temperature. However, the change of acceleration with reduction in ground temperature follows a pattern of decrease-increase-decrease and then tends to be stable.

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