Characteristics of Earthquake Distribution in Kunlun Mountains and Designs of Qinghai-Tibet Railway Engineering

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ABSTRACT :

At 17:26, 14th, Nov. 2001, an earthquake of Richter magnitude 8.1 happened at N36.2° and E90.9° in the west of the Kunlun Mountain Pass, which was the heaviest one in terms of magnitude in the past 50 years in the mainland of China, caused by the Kunlun Mountains Pass Fault. The fault was a left-lateral strike-slip reversed fault with a dip direction of N80°W and dip angle of 50°～78°, which was 100~200m wide. A surface fracture zone about 426 km in length along the fault developed from east to west about 70km to the east and 350km to the west of the Qinghai-Tibet highway came into being. The fracture zone was consisted of a series of pure shearing strike-slip fractures with feather form. The maximum width of the fracture zone was 32m, the maximum horizontal displacement of the ground fissures was 6.4m and the maximum vertical displacement was 4m. Many bulges with several meters high on the discontinuous steps and fissures with tens of meters in depth were appeared. Basically the seismic intensity is Ⅷ in the region. The Qinghai-Tibet railway has been designed according to the aseismatic criterion of railway construction. The railway line was designed to cross the earthquake fault with large angle by embankment and culvert, without large structures such as bridge within 600m far from the fault. In this paper the distribution characteristics of the earthquake in Kunlun Mountains and the designing work of the Qinghai-Tibet railway engineering were presented, and the safety of the railway was evaluated.

KEYWORDS: Qinghai-Tibet Railway; active fracture; engineering evaluation; earthquake, surface fracture zone

The Golmud-Lhasa railway, part of the Qinghai-Tibet railway, with length of 1142km, started to be constructed on 29th, June 2001, completed and was opened to traffic on 1st, July 2006.

The Tibetan plateau is a continent region with the largest scale, the highest elevation and the most intensely tectonic activity. Here exist lithostratigraphic and multi-phase regionally tectonic events in Proterozoic, Paleozoic, Mesozoic and Cenozoic with prolonged and complex geology evolution history and tectonic deformation process. Gradually unique crustal structure and plateau landform framework are formed. In the Tibetan plateau, there is intensely tectonic and seismic activity with many times heavy earthquake activities in geologic history.

At 17:26, 14th, Nov. 2001, an earthquake of Richter magnitude 8.1 happened at N36.2° and E90.9° in the west of Kunlun Mountain pass. The earthquake has been the heaviest one in terms of magnitude in the past 50 years in the mainland of China, and was originated mainly from Kunlun Mountains Pass fault(KMPF). A surface fracture zone about 426km in length developed from east to west along the fault.

After the earthquake, we have carried out the geological survey and investigation in the seismic zone and neighboring regions to primarily obtain the characteristics of seismic fault and surface fracture zone, etc, and provide the basis for the design of Qinghai-Tibet railway.

This earthquake had a certain influence on construction of the Qinghai-Tibet railway. It's important for the Qinghai-Tibet railway design of anti-earthquake in the region whether or not to modify the basic seismic intensity and antiseismic intensity of railway, and so on.

1. BASIC CHARACTERISTICS OF SEISMIC FAULTS

After the earthquake of Richter scale 8.1 happened, a surface fracture zone about 426km long along the fault was formed. After the survey and research on the surface fracture zone, we think that its location is completely consistent with the KMPF, which crosses the Qinghai-Tibet highway from east to west and their dislocation characters are same completely. In other words：the fault is the seismic fault which develops nearly from east to west direction and locates at the southern foot of Kunlun mountain.（Figure 1.1）。Characteristics parameters of seismic fault (the KMPF) are listed in the table1.1.

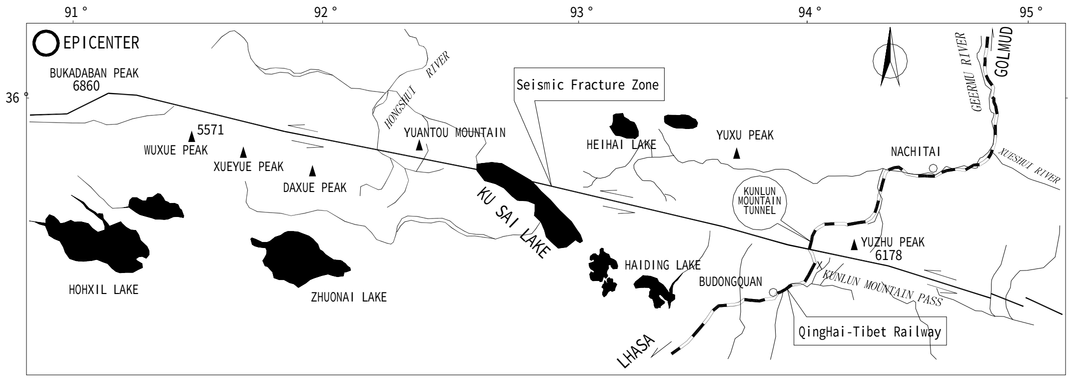


Figure 1.1: Sketch map of the KMPF

Table 1.1：Characteristics parameters of seismic fault

Strike of fault	N80°W	Angle of seismic fracture zone across railway	50°
Dip of fault	N	Maximal vertical displacement of surface crack	4m
Inclination of fault	50°~80°	Maximal horizontal displacement of surface crack	6.4m
Length of fault	>300km	Maximal width of surface crack	4m
Geological period	Q_4	Maximal width of seismic fracture zone	32m
Character of movement	Sinistrally strike-slip and horizontal fault	Angle of seismic fracture zone across highway	90°
Slip velocity	10.7±3.2mm/a	Course of seismic fracture zone across highway	GK2894+000
Course of seismic fracture zone across railway	DK979+528	Paleo-earthquake	Happened
Coordinate of seismic fracture zone across railway	E94°03.171' N35°40.314'	Mode of destruction	sinistrally strike-slip surface fracture

The measurable parameters, for example: surface fracture form and offset at the crossing-point of seismic fracture zone and railway, were consistent with the results of seismic activity and fracture behavior in *Report About Active Faults Of Important Region Along The Qinghai-Tibet Railway Across The Tibetan Plateau* (by China Seismological Bureau, 2003), and also consistent with the information of areal geology in this region. The impact of seismic fault had been considered in seismic design of Qinghai-Tibet railway.

2. MOVEMENT CHARACTERISTICS OF KMPF IN LATE-QUATERNARY

The KMPF, is an active fault at the south of Nanshankou and Kunlun Mountain pass, which can cause the earthquake. It is also a sideline fault between Bayankala-Qiangtang block and Chaidamu block, an important part of active fault at the south foot of Kunlun Mountain, which distributes from the neighborhood of Bukadaban peak in the west to Dari county in Qinghai province to the southeast.

The KMPF is obvious on the airscape and satellitic-photoes with the linearly continuous broken cliffs and the landform of the northern section (upside) differing from the southern section (downside) of the fault. The uplifted north part became Kunlun Mountain with perennial snow, and southern part became gentle intermountain valley. The movement characters of the fault are blurry in the 5~15 km section to the west of Qinghai-Tibet highway. Taking it as a boundary, there are some small dislocation steps between the outstretched line of the eastern section and that of the western part.

A great deal of pressure ridges distribute linearly along the KMPF, accompanied by varieties of seismic fractures patterns, seismic scarps and pull-apart-basins. The phenomena of the KMPF zone, such as, all gullies sinistrally offset, sinistral displacement of all fault scarps on multilevel terraces and scarps between high-terraces and low-terraces the reverse scarp formation due to raise of southern parts of fault in local regions, Paleo-earthquake deformation, and so on, show that the KMPF is really an active fault since Holocene-epoch.

The first and second terraces of the Baladacaiqu River, located in the neighborhood of 24km distance to the west of Kunlun mountain pass., are flat and wide. This seismic ground fracture zone sinistrally cut the Baladacaiqu river and its first and second terrace, and the surface fracture zone with maximum width of 32m, totally in the direction of N80°W was formed , which is composed of the secondary purely shearing strike-slip faults of direction N80°E, tensile-shearing strike-slip faults of direction N72°～75°E in feather or en-echelon pattern . The secondary faults are all diagonal to right-hand side with discontinuous segment forming ground bulging of 1~2m in height. Some of the secondary faults are diagonal to left-hand side with discontinuous segment forming pull-apart-basins or fault groove of 2~3m in depth and 1~1.5m in width, in which there are two approximately parallel secondarily tensile-shear faults, located at N35°41.882' and E93°48.729' in direction of N72°～75°E, to form the seismic fracture zone with width of 7.5m. The secondary faults in the south were sinistrally cut with 1.7m width and 2.1m offset ;the secondary hypo-faults in the north rose with 0.3m offset and a little thrust displacement. The ground fracture was of a total character that the north part uplifted and the south-side declined comparatively with about 0.4m difference displacement.

At 5km distance east to the Qinghai-Tibet highway, there was a third terrace of gully sinistrally cut by the seismic fracture belt. The dislocations of the third and second terrace were separately 37±2m. The fine sand samples from the first terrace and top of the second terrace were tested by thermo luminescence and it was shown that their ages were separately 4880±380a and 2640±210a up to now. Based on the above, we can calculate that the velocity of sinistral strike-slip of KMPF is 10.7±3.2mm/a at the site.

All the data show that the KMPF is an active fault since Holocene-epoch. The seismic fracture zone with sinistrally strike-slip thrust displacement is superimposed on the sinistrally strike-slip fault scarps. It's shown that many paleo-earthquakes with the ground fracture zone along the KMPF happened in Holocene-epoch.

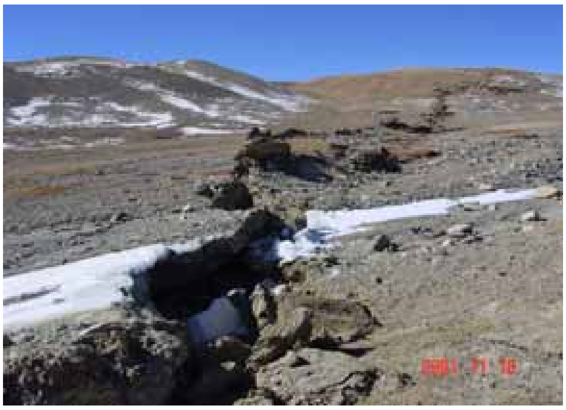
3. DISTRIBUTION CHARACTERISTICS OF SEISMIC FRACTURE ZONE

3.1 Basic characteristics of seismic fracture zone

A large ground fracture zone along the fault appeared after the earthquake. Based on the investigation data, the seismic fracture zone distributes from east to west with the length of 426km.

There are secondary fractures at the both two ends of fracture zone which make the existed KMPF develop again. At the 4 km distance north to Kunlun Mountain pass the ground fracture athwart crosses the Qinghai-Tibet highway and railway in the direction of N80°W with strip-shape distribution. The seismic fault totally inclines to north with 50°～78° inclination. The surface fracture zone , with maximum width of 32m, maximum horizontal displacement of 6.4m and maximum vertical displacement of 4m, is composed of series of purely shearing and strike-slip faults of direction N80°W in the feather pattern. The discontinuous steps swell up to bulges with several meters high or stretch into recessed cracks with dozens of meters in depth (Figure 3.1). All such structural forms demonstrate significant views.

(a)



(b)

Figure 3.1：Distribution characteristics of surface fracture zone in Kunlun Mountains
（a） configuration of surface fracture zone；(b) distribution of surface fracture zone

3.2 characteristics of seismic surface fracture zone near the Qinghai-Tibet railway under construction.

The KMPF near the Qinghai-Tibet highway under construction is located in the south slope of the Kunlun Mountains. The Course of surface fracture zone across railway is DK979+528 with 50° angle and the coordinate is N 35°40.314’ and E94°03.171’（Figure 3.2）. The width of surface fracture zone is 15~20 m near the railway. The fault plane is steep and approximately vertical, and the tensile faults develop in direction of N50°E in patulous en-echelon pattern . Tensile offset of each fault is 1.2~2m with maximal depth of 4.4m. There are seven secondary faults on the road surface of under-construction railway with sinistral offset of 0~0.5m and width of 23.5m.

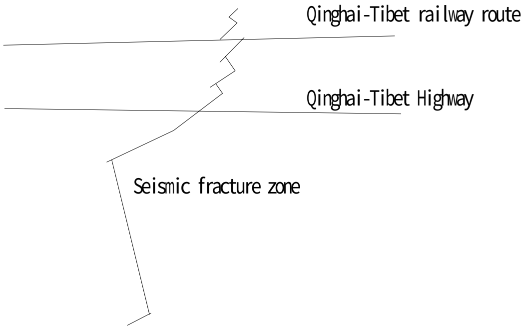


Figure 3.2：Photo and sketch map of the seismic fracture zone near the railway

According to the configuration of seismic fracture zone, geography position, the round-inflexion of tensile fault and increase of tensile quantity along slope, etc, it is shown that there is a little gravitational sliding function in the period of seismic faults movement, so that the ground fracture is enlarged increased greatly at this zone.

3.3 Characteristics of seismic surface fracture zone near the Qinghai-Tibet highway

The course of fracture zone across the Qinghai-Tibet highway perpendicularly is GK2894 +000.The road surface humped and the structure was damaged near the site. The ground fracture zone is 7.9m in width in the west of the highway, in the direction of N85°W and across an icing stream, ice-surface cut broken with sinistral dislocation of 4.8m between east and west bank(Figure 3.3), running from south to north.

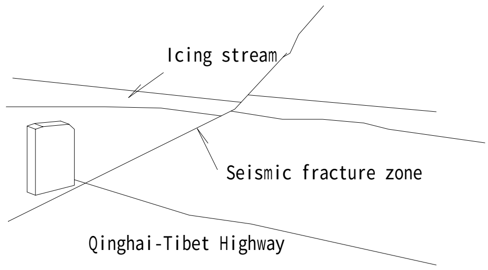


Figure3.3：Photo and the sketch map of the sinistral offset of the icing-stream near the highway

On the hillside inclined to south in the west bank of the stream, the seismic fracture zone is about 15m width with the north part of fault uplifting a little. 7~8 small gullies were consistently cut sinistrally with dislocation of 3.8~4m, in which the new fault plane strike is 12°∠78° and the scratch plunge angles is 28°.

In the east of the highway, the seismic fracture zone is of 13.5m width, composed of secondarily strike-slip faults in feather pattern in direction of N80°W, and the pressure bulges distribute along sinistral fracture, whose edge is totally controlled by arc-shaped thrust fault in direction of N40°E with 1.1m height . Sinistral dislocation can also be seen at the east bank of a gully with 4m offset.

The Qinghai-Tibet highway is cut by surface fracture zone of 25m in width, in which the four major secondary faults develops. Although their sinistral offsets of the four secondary faults are small, the total seismic offset at both sides of the fracture zone reaches about 4m.

4 INFLUENCE AND ESTIMATION OF EARTHQUAKE TO THE QINGHAI-TIBET RAILWAY

The epicenter of Ms 8.1 Kunlun-mountain earthquake is located in Kusai Lake according to seismological survey, Bukedaban Peak according to seismograph records and at 36.2° north latitude and 90.9° east longitude (by China Seismological Bureau, 2003).

The Qinghai-Tibet railway began to be constructed on 29th June, 2001. When the earthquake occurred, the Kunlun Mountain tunnel was being constructed and other projects such as embankment, bridge and culvert were not. The railway construction company had a stationed place where the tabernacles and the brick bounding walls were built. In addition, there was Xidatan oil-reservoir station (about 10km distance to the 2894km milestone of the Qinghai-Tibet highway) with three–storey building and brick bounding walls

In order to estimate the influence of earthquake on the Qinghai-Tibet railway engineering, we have carried out investigation and research on the surface fracture zone. Taking the intersection of the surface fracture zone and the Qinghai-Tibet highway(2894km milestone) as a base point, we have carried out spot research on surface fracture zone 50km eastward and 50km westward . It's shown that the seismic fracture zone attenuates gradually from west to east.

In addition, we repeatedly investigated the main seismic damage sections from Nanshankou to Qingshuihe along the Qinghai-Tibet railway and analyzed the attenuation rule of seismic damage considering the under-construction railway, temporary facility, residential points and pipe laying, etc.

According to the above condition，the influence of the earthquake on the Qinghai-Tibet railway is as follows.

4.1 The seismic faults

The occurrence period of earthquake of the KMPF is 1,800±800a. Therefore, after the Kunlun-mountain earthquake happened, the KMPF would become a comparatively steady fault, and the occurrence possibility of the intensive earthquake in next 100 years is small. So we can think that the probability of larger earthquake will decrease greatly at the northern sections of the Qinghai-Tibet railway.

4.2 The basically seismic intensity

The basically seismic intensity is Ⅷ in this region. Within the scope of around 14 km near the Kunlun mountains pass and milestone GK2894km of the Qinghai-Tibet highway, the factual intensity reaches Ⅸ~Ⅹ, within 30km from Budongquan to Qingshuihe, it was also over Ⅷ. They are separately more than the basically seismic intensity in the region.

By the research results of Chinese National Seismic Intensity Evaluation Committee, the exceeding probability of this earthquake is 10%. It means that the probability of seismic intensity over Ⅷ is 10% in 100a. It is possible that the factually seismic intensity is larger than the basically seismic intensity, but its probability is only 10%. Therefore, it is an infrequent incident as well as a usual incident that the factually seismic intensity is more than the basically seismic intensity. There are many examples, such as Tangshan earthquake in 1976. The measured value of seismic intensity in Tangshan city is Ⅹ and the basically seismic intensity keeps Ⅷ. Besides that, in the region of Linfen county, Shanxi, the two earthquakes over Richter scale 8 happened in 1303 and 1695. So we can say the large earthquake occurs frequently, but the basically seismic intensity is still Ⅷ.

Although the earthquake of Richter scale 8.1 happened just now in the region and factually seismic intensity was larger than the basically seismic intensity, we can determine that the probability of the large earthquake occurrence of the Kunlunshan fault, at the southern foot of the Kunlun Mountain, is much lower within a long time than that before the earthquake. The basically seismic intensity still keeps the Ⅷ in the Kunlun Mountain region.

4.3. The seismic disaster

Because magnitude of the earthquake is large, the ground fracture zone is of great length, the tabernacles of railway is relatively near to the seismic fracture zone, tabernacles and temporary facility suffered from seismic tremor greatly. As a result the cracks of houses appeared, or the houses were destroyed, even a few houses fell in and bounding walls collapsed badly. The under-construction railway, 300 km to the east of highway, and the section of GK2894km of the Qinghai-Tibet highway crossed the ground fracture zone, the road surface was destroyed badly.

There are various damage caused by earthquake. The estimation is present in terms of characteristics of construction structure in following paragraph as follows.

（1）tabernacles

Through the investigation, the obvious weakness of each collapsed house including the seriously or moderately damaged is as follows: First, the bay is too large and there are few partition walls. Second, mixed mortar of low quality is used on some tabernacles. If all the buildings could be built according to the rule for anti-earthquake, the buildings would not fall in and the degree of damage to construction would be greatly reduced.

（2）bounding walls

In the earthquake, it was a universal phenomenon that the bounding walls fell in. From Xidatan to Wudaoliang, many of bounding walls collapsed. Particularly, the bounding walls around stationed-place and Xidatan oil-reservoir were destroyed badly.

The main reason was not the poor quality of bounding walls but predominant period of ground movement, which was close to the natural vibration period of bounding walls so as to produce resonance. The epicentral distance of the earthquake was far away with the deficient high frequency of seismic wave and the plentiful low frequency. To bounding walls, the longer the walls are, the lower the natural vibration frequency would be. So it was easier to produce resonance with seismic wave of low frequency. The factually seismic damage has proved the above explanation. The longer the bounding walls, the larger the degree of collapse of the bounding walls. Otherwise, it was not.

4.4 Estimation to seismic design of the Qinghai-Tibet railway engineering

The aseismic design of the Qinghai-Tibet railway in this region is based on the predictive value of hazard of KMPF (by China Seismological Bureau, 2000), which is consistent with the measured value（Table 4.1）.The railway gets across the fault zone with lange-angle, within the influence scope of fault large constructions are not built, but completely subgrade and culvert are built. That meets *Code for Seismic design of railway Engineering*. So the aseismic design of the Qinghai-Tibet railway in this region is completely consistent with measured value of earthquake and it is not necessary to revise the parameter of aseismic design.

Table 4.1: Contrast between predictive value and measured value about hazard of KMPF

Reference item	Predictive value	Measured value
Probability of earthquake	The great possibility of earthquake with ground fracture in 100a	earthquake with ground fracture occurred at 14th ,Nov.2001
Upper limit of earthquake magnitude	Ms=8	Ms=8.1
Movement mode	sinistrally strike-slip & a little thrust displacement	sinistrally strike-slip & a little thrust displacement
sinistral offset at intersection of fault and railway under construction	4～5m	3.8～4m
vertical displacement at intersection of fault and railway under construction	about 1m	0.1～0.5m

5. SEISMIC DESIGN OF THE QINGHAI-TIBET RAILWAY ENGINEERING

（1）Qinghai-Tibet railway engineering is designed based on Code for seismic design of railway engineering in the region .The basically seismic intensity is determined as Ⅷ.

（2）Within the affected areas of the fault, the railway was designed to cross the fault zone with large angle. The angle between the two was 50°. Large constructions were not built, but embankments and culverts were built within 600m distance of fault.

（3）Out of the affected areas of the fault, the important projects in Kunlun mountains, for example the Kunlun Mountain tunnel, were designed to resist earthquake of seismic intensity Ⅷ, and corresponding strengthening aseismic measures were adopted.

On the whole, the aseismatic design of the Qinghai-Tibet railway engineering is feasible, and the railway line is safe.

6. CONCLUSION

6.1 The Kunlun-mountain earthquake has been the heaviest one in terms of magnitude in the past 50 years in the mainland of China. The seismic fault is the KMPF. It is an active fault since Holocene-epoch, which is a horizontal fault of sinistrally strike-slip character with the maximal horizontal displacement of 6.4m, the maximal vertical displacement of 4m and a little thrust displacement. Since Holocene-epoch, many paleo-earthquakes have happened which cause the ground fractured along the KMPF.

6.2 After the Kunlun-mountain earthquake happened, the KMPF became a comparatively steady fault with smaller possibility of large earthquake in next 100 a. In addition, the probability of large earthquake will decrease greatly at the northern section of the Qinghai-Tibet railway.

6.3 Although the factual seismic intensity of Kunlun-mountain earthquake is larger than the basic intensity of the region, the seismic intensity can be considered to be stable as Ⅷ in value.

6.4 The design basis of the Qinghai-Tibet railway was completely consistent with the measured parameter. The intensity of this earthquake was high, formed a huge zone of fracture, made the tabernacles and temporary facility of railway under construction destroyed seriously. Therefore, all of constructions in the region should be built strictly based on the *Code for seismic design of railway engineering*, so that the seismic disaster can be reduced greatly.

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