REPETITION OF STRONG EARTHQUAKE AND REDUCTION OF SEISMIC RISK

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In 1957, the first seismic risk zoning map of China was published[1]. The two principles of making the map were stated as follows.

1.The earthquake magnitude which appeared in history will repeat again in future.

2.Similarity of seismotectonics is corresponding with the similarity of earthquake magnitude.

The above mentioned principles have some insufficiencies. In this paper, some improvements on the seismic risk zoning have been discussed.

REPETITION OF STRONG EARTHQUAKE

In our country, repetition of strong earthquake is very important for seismic risk zoning.This problem may be discussed by the following methods.

1.Statistic method

The Chinese civilization is one of the oldest in the world.We have not found repetition of earthquakes of magnitude ($M\geqslant 7$) in the Shanxi-Gansu-Ninxia region, during about 2000years in history.* Besides, in the eastern part of the mainland of China, there are similar results. There the definition of repetition is the superposition of the projection area of the earthquake source volume.The long and short axis of the area are specified by the following formulas:

The long axis. $$L(km)=10^{\frac{M-3.3}{2.1}} \quad (1)$$

* 兰州地震大队，陕甘宁三省地震迁移现象的讨论，地震烈度资料汇编，1971.

The short axis: $L'(km) \approx \frac{1}{2}L$ (2)

2.Dislocation method

In 1973, we proposed a formula for calculating the repetition period T of strong earthquake as follows[2]

$$T = \frac{D}{V} \quad (3)$$

$$D = 10^{0.52M-1.15} \quad (4)$$

where D is slipping amplitude in earthquake source in unit of cm.

According to statistics of the slipping rate of fault and contrast motion in many places of China, the largest slipping rate is 25 mm/year, the least slipping rate is 0.1 mm/year and the average rate is 10 mm/year. We substitute these data into the formulas (3—4) to get the repetition periods of strong earthquakes having difference magnitude as shown in table I. T_1 is the least period calculated by the largest rate, T_2 is the moderate period calculated by the average rate, and the T_3 is the longest period calculated by the least rate.

3.Heat conductivity method

When a strong earthquake occurred, the source fault heated due to frictional action and insertion of high temperature substance.In this case, stress can not be accumulated again in earthquake source untill the high temperature reduce to that value which is equal to the surounding medium.In our previous book[8], the repetition period of strong earthquake is described by the following

Table 1 The repetition period of strong earthquake

M	D (cm)	T_1 (year)	T_2 (year)	T_3 (year)	remak
8.5	14800	592	1480	148000	
8.0	8130	325	813	81300	
7.5	4460	178	446	44600	
7.0	2460	98	246	24600	
6.5	1350	54	135	13500	
6.0	740	30	74	7400	

$$T = t_1 + t_2 \quad (5)$$

where t_1 is time interval of the heat dispersion, t_2 is time interval of the elastic strain energy accumulation. Due to that the thickness H of the high temperature layer in earthquake source is difficult to be determined, we can not get the t_1. However, formula (5) means, the period calculated from (3) trends towards safety.because in formula (3), t_1 is not considered. It should be pointed out that we might use the modulation of solid tide to check up the situation of earthquake source since earthquake occurrence. If the high tides often coincide with the small shocks, we recongnize the source region not to be sticked, namely, the source region is in stage t_1.

REDUCTION OF SEIMIC RISK*

In the mainland of China, the principal pressure stress direction is about uniform and regular. In this case, the lateral direction of dislocation of both parallel strike faults are similar. If a strong earthquake occurred in one of them, the seimic risk in other one is reduced at once, as shown in Fig. 1. In this figure A B and C D is two faults. The stage without stress is shown by Fig. 1 a, the shearing stage is shown by Fig. 1 b, and the stage of generating earthquake on C D is shown by Fig. I C After this stage the seismic risk on fault A B is reduced. If two parallel faults have the contrary lateral direction, when a large earthquake occurs along one of them, the seismic risk on the other fault will be increased.

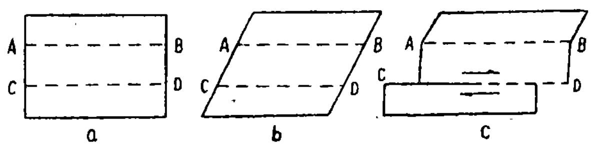

Fig. 1 Three stages of earthquake process.
a. stage without shear strain.
b. stage having shear strain.
c. an earthquake takes place on fault C D.

If we regard the distance on which the horizontal displacement is equal to 1 m as the farthest limit of reducing seimic risk for long time, and the depth of lower edge of fault plane C D is 20 km, we can get the distance R of reducing the seismic risk in unit of Km as the following formula:

$$R = \frac{20}{1.17} \cot\left(\frac{\pi}{2} \frac{100}{D}\right) \quad (6)$$

where D is the same as that in formula (4). From (6) and (4) we may determine R for earthquake with different magnitude as shown in table2.

Table 2
Earthquake magnitude(M), Amplitude of dislocation (D) and reducing earthquake distance(R)

M	8.5	8	7.5	7.0
D(cm)	1480	813	446	246
R(km)	160	90	50	25

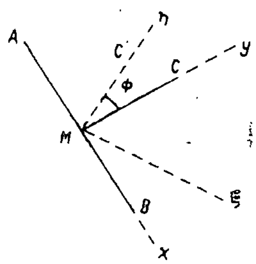

Fig. 2 Junction of both faults CM and AMB. Dotted Line is oblique fault.

* 郭增建、秦保燕，平行断层之间的相互影响—减震作用，青藏高原第一次地震学术讨论会论文，1984.

According to the combination model[2], the length l along which the seismic risk is reduced equals L in formula (1) at least. If on the light of the elastic dislocation theory, the l is shorter than that above mentioned. As for the duration of reducing seismic risk may be juged by the repetition period of strong earthquake (Tablel).

The junction of both faults is shown in Fig.2. C M and A M B are two faults which are on axises x and y. For the convenience of calling, we name the fault M C "perpendicular fault" and the fault A M B "bottom fault". When a strong earthquake occurred in bottom fault, the seismic risk in perpendicular fault is reducecd, while a strong earthquake occurred in perpendicular fault, the bottom fault may appear strong earthquake some time later.

According to elasticity theory, when a slipping takes place on AMB, shear stress τ_{XY} on fault M C will be relieved, because:

$$\tau_{XY} = \tau_{YX} \qquad (7)$$

and shear stress $\tau_{\xi\eta}$ on the oblique fault M C′ will be relieved as:

$$\tau_{\xi\eta} = -\frac{\tau_{XX} - \tau_{YY}}{2}\sin 2\varphi + \tau_{XY}\cos 2\varphi \qquad (8)$$

EXAMPLES OF REDUCING SEISMIC RISK

1. The 1604 Quanzhou earthquake The Quanzhou earthquake is located in eastern sea off Quanzhou and has maghitude of 8. Its meizoseismal area is parallel to the Changlao-Nan′ao fault, as shown in Fig. 3.

It is interesting that the Changlao-Nan′ao fault is geologically active, but there is not any strong earthquake to occur in history. We think the seismic risk in this fault is reduced by 1604 Quanzhou earthquake.

2. The 1833 Songming earthquake The Songming earthquake has magnitude of 8. It′s meizoseismal area is extended northsouth, as shown in Fig. 4. It should be pointed out that several geologically active faults are

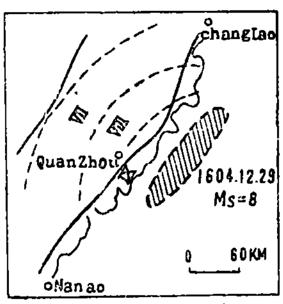

Fig. 3 Seismic risk of the Changlao-Nan′ao fault is reduced by the 1604 Chuanzhou earthquake.

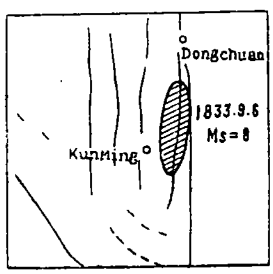

Fig. 4 Seismic risk on Parallel fault is reduced by the 1833 Songming earthquake.

parallel to the meizoseismal area of the Songming earthquake. There is not any strong earthquake to occur along these faults. We consider that the seismic risk on these faults is reduced by the 1833 Songming earthquake.

Besides, there are many of similar examples in other places of the mainland of China.

3. The 1668 Tancheng earthquake (M = 8.5) The Tancheng earthquake is located on the great Tancheng fault, and its meizoseismal area is extended in direction N N E, as shown in Fig. 5. An active fault having extend N W makes a junction with the Tancheng fault. According to the above mentioned viewpoint (Fig. 2), when the 1668 earthquake (M = 8.5) occurred, the seismic risk on the fault of N W has been reduced. In fact, there is not any strong earthquake to occur on the fault of N W sc far.

4. The 1976 Tangshan earthquake (M = 7.8) The meizoseismal area of the Tangshan earthquake has a trend of N E. After it occurred, there is not any strong earthquake to follow in the fault parallel to the Tangshan earthquake fault, but two strong earthquakes occurred in that fault which is about perpendicular to the Tangshan earthquake fault, as shown in Fig. 6.[4]

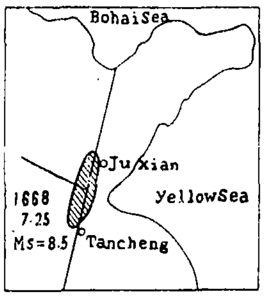

Fig. 5 Seismic risk on fault of direction N W is reduced by the 1668 Tancheng earthquake.

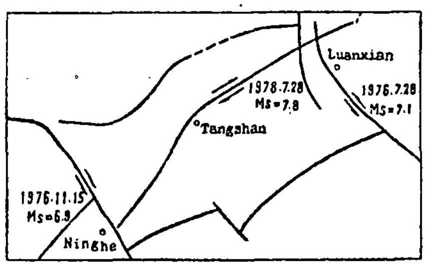

Fig. 6 Redution of seismic risk and following strong earthquake after the 1976 Tangshan earthquake (M_S = 7.8).

5. The two 1976 Yanyuan earthquake The first earthquake (M = 6.7) took place on Nov. 7, 1976, the second one (M = 6.4) took place on Dec, 13, 1976. Their earthquake source fault and isoseismal are shown in Fig7.[5] It is interesting to note that the first earthquake is in a perpendicular fault, the second earthquake is in a bottom fault.

Fig. 5, 6 and 7 show that in the junction of faults, the order of earthquake occurrence is that in the perpendicular fault is earlier that in the bottom fault.

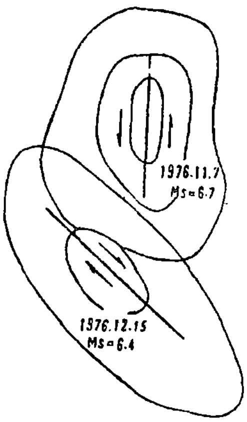

Fig. 7 Two strong earthquakes of 1976 in Yanyuan region.

DISCUSSION

From the reducing earthquake theory, the seismicity pattern on parallel faults is usually parallelogram such as the distribution of strong earthquakes in Gansu province and Ningxia region, as shown in Fig. 7.

According to measurement of stress on both sides of the great Tancheng-Lujiang fault along which the great Tancheng earthquake of magnitude 8.5 took place in 1668 year, the stress decrease curve with distance from the fault is shown in Fig.9. (after Ding Xuchu and Liang Haiging)

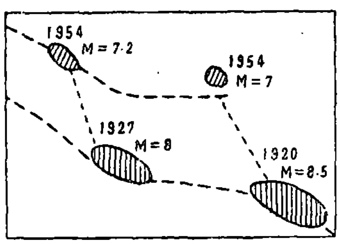

Fig. 8 Parallelogram distribution of strong earthquakes in the Gansu and Ningxian region.

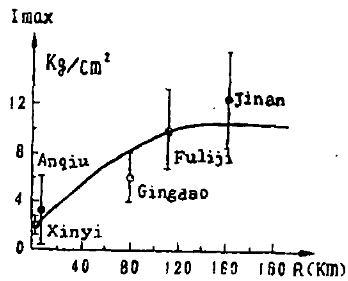

Fig. 9 The relation between maximum stress and distance from the fault in the middle segment of the Tancheng-Lu Jiang fault

From this figure, we can see that the stress decrease is clear until to the distance of about 160 km from the fault. It is coincident with the formula (5) and table 2.

If a long fault creeps, it can reduce the seismic risk in other faults which are parallel to the creep fault.

In the light of reducing earthquake theory, earthquake activity belt may migrate parallelly towards its sides at certain distance.

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大震重复性与减震作用

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摘　　要

1957年公布的中国地震烈度区划图其编图原则有两个，一个是过去历史上发生过多大的地震，将来还会重演，另一个是地质条件相似的地方地震强度相似。本文对这两个原则进行了修正。对第一个原则的修正主要是用统计法、位错法和热传导法求出大震重复周期，在大震间歇期间，烈度可以降低一两度。对于第二个原则的修正主要是考虑到我国大陆内主应力的分布是大体一致的，错动旋性也是一致的。在此情况下，当一个断层上发生大震后，相距不太远的平行断层就会减震，而不是地质条件相似必然要发生类似的大震。对于相交汇的两个断层来说，一个相当于垂线，可称垂断层，另一个相当于底线，可称底断层。如果底断层发生了大震，则垂断层上就减震了，简称“底震垂减”；如果垂断层上发生了大震，则底断层上可能还会相继发生大震，可称“垂震底继”。根据减震作用的观点可以在全国寻找一些安全区，以利于经济建设。如果一个断层不是发生大震，而是在很长的地段内发生蠕滑，则相邻的平行断层也可减震。由减震作用可以解释地震活动的整带跨距迁移，也可解释相平行的断层上的地震分布的平行四边形格局。为了探明已发大震的断层是否已锁住，可用被外因调制的小震活动性来抽查。对于平行断层来说，异旋是加震的。

本文得到的主要结果如下：

1．大震重复时间　本文收集了中国活动断层滑动速率的数据，得到了最大滑动速率为25mm/年，平均滑动速率为10mm/年，以及最小滑动速率为0.1mm/年。据根我们在1973年得到的震级与错动幅度的经验关系式

$$D_{cm}=10^{0.52M_s-1.25}$$

则强震的重复时间可分别表示为：

$$T_1=\frac{D_{cm}}{V_{最大}}$$

$$T_2=\frac{D_{cm}}{V_{平均}}$$

$$T_3=\frac{D_{cm}}{V_{最小}}$$

表 1　大震重复时间

Ms	D(cm)	T₁(年)	T₂(年)	T₃(年)
8.5	14800	592	1480	148000
8.0	8130	325	813	81300
7.5	4460	178	446	44600
7.0	2460	98	246	24600
6.5	1350	54	135	13500
6.0	740	30	74	7400

式中V为滑动速率。由上述数据可求得在不同滑动速率下的大震重复时间，如表 1 所示。在不同的建设地区，可根据其建设项目的重要性以及当地活动断裂的大致滑动速率来选择表

1中的大震重复时间。

2.强震造成的减震距离 对于一个走滑震源断层，在其垂直方向上位移衰减至1米的距离R为

$$R=\frac{H}{1.17}\cot\left(\frac{\pi}{2}\ \frac{100cm}{Dcm}\right)$$

上式H为断层面深度，我们取20公里，则上式可写为

$$R=\frac{20}{1.17}\cot\left(\frac{\pi}{2}\ \frac{100}{D}\right)$$

对于不同震级地震的减震距离可表示于表2

表2 不同震级的强震的减震距离

Ms	8.5	8	7.6	7.0
R(km)	160	90	50	25

关于由热传导计算大地震重复时间问题留待以后专文讨论。

研究报道

鄂尔多斯块体南缘发现国内罕见的史前大地震形变带

为执行国家地震局“鄂尔多斯周围断陷盆地现今活动特征及其大震重复关系的研究”这一重点科研项目，兰州地震研究所与陕西渭南地区地震办公室组成联合考察队，对韩城地区活动性断裂带进行实地考察。最近在韩城市西原村的西山，发现一处罕见的史前古地震遗迹，由地震陡坎、地裂缝、地震凹地、基岩滑坡和崩塌等现象组成一条走向北东40度，长达3000余米、宽300余米的形变带。

古地震形变带不受地形约制，错断山梁，跨越沟谷，在宽300米的范围内即有8条地震裂缝和地震陡坎。地裂缝一般宽30—50厘米，最宽达3米，深不见底，並显示张性左旋的水平错动。地震陡坎一般高1.5—2米，最高达6米，犹如长城蜿蜒于山脊之上。地震形变带南部为奥陶纪灰岩与第四纪黄土构成的正断层，其北侧为奥陶纪灰岩与石炭纪砂板岩煤系地层构成的逆断层。

根据该形变带的强度和规模分析，並与国内外在本世纪所发生8级以上大震形成的地震形变带进行对比，这次古地震的震级在8级以上。虽然地震陡坎及地裂已将晚更新世和全新世黄土错断，但自有地震记载以来，韩城和周围各县以及距震中200余公里的古都长安均都无该次地震的记载，因此目前我们正对其发生年代进行深入的研究，並继续对延伸规模进行追索。

韩城史前古地震形变带的发现，对研究韩城活动性断裂带现今地震活动和汾渭地震带的大震复发周期有着重要的意义。由于该地震形变带展布于奥陶纪灰岩中，不易侵蚀风化，又处于峻峭的高山之顶，无人为破坏，遗迹保存完好，各种地震现象清晰醒目。尤为难得的是在古地震形变带250米以下，有一个引水涵洞横穿整个山体，涵洞内可以直接观察到地面形变带延伸于地下的许多珍贵现象，为观测、研究地震提供一个立体图景。这一得天独厚的优越条件，也为中外地震学家深入研究地震地质、地震工程、震源物理和地震预报等提供了难得的场地。 （兰州地震研究所 **冯学才** 陕西渭南地震办 **姚兆瑞**）