第10卷 第2期　　西北地震学报　　Vol.10, No.2
1988年6月　NORTHWESTERN SEISMOLOGICAL JOURNAL　June, 1988

MODEL SYSTEM OF EARTHQUAKE PREDICTION AND COUNTERMEASURES

Tan Chengye
(*Seismological Bureau of Yunnan Province*)

A model system of earthquake prediction and countermeasure is designed. The necessaries, conditions, designed ideas, constructions, functions, compositions of the model system and applied mathematical methods are discussed in this paper.

It is impossible to treat the large system with complex constructions and multiple functions by using a single model because the variables are confined in a single model. The earthquake prediction and countermeasure investigation system which includes long-term, middle-term and short-term prdiction, strong aftershock prediction, earthquake decision making, contains multiple targets, functions and levels. It is necessary to solve this problems by using the model system not by using a single model.

The idea of model system maintains to design and establish models using system engineering methods. Outputs and inputs of several models are matched each other and the functions of them are complemented each other.

Up to now, experiences on earthquake prediction accumulated are insufficient for establishing an expert system of earthquake prediction. To study systematically and comprehensively the earthquake characteristics of every modes in several areas, refine various criteria of earthquakes and establish model system solving problems of earthquake prediction and decision making are needful.

Functions of this model system may be divided into two groups:

1. The earthquake prediction functions

a. Recognizing earthquake risk in ranges and province;

b. Recognizing middle-term (0.5-5 years) earthquake risk;

c. Recognizing short-term (0.5-6 months) earthquake risk;

d. Recognizing imminent (hours-15days) earthquake risk;

e. Recognizing the modes of coming earthquakes;

analysis of shock sequence trend. If the genesis of a variety of sequence types is known, the recognization of earthquake process can be promoted and it is useful for progress of earthquake prediction.

Asperity model is used to mainly explain foreshock and mainshock[1-3] of plate boundaries and Barrier model is used to explain mainshock and aftershock[1,4,5]. In order to inquire into the possible genesis of intraplate earthquake sequences, based on Barrier model and the analysis of actual data of earthquakes which occur in China, we propose another heterogeneous body model-Obstacle model. It differs from Barrier model in the following aspect: the earthquake source area, in Barrier model, is acted by uniform stress before mainshock, the occurring of mainshock makes heterogeneous bodies produce, so it is used to explain the occurrence of aftershock; the obstacle model mainly shows that there are heterogeneous bodies in rock medium before mainshock occu rring, besides the heterogeneous bodies in rock medium which formed by mainshock. It is proved by a lot of fact of geophysics. So, obstaclemodel is actuallyexpansion and perfection of the Barrier model further. Obstacle as heterogeneous body of earth medium is either the high strength area on the fault plane, or the special area where its strength is similar but the structure is different.

In order to know the substance of obstacle, we have done the experimental research[6-9], and got the satisfactory results. In order to understand the properties and effect of obstacle, inquire into possible genesis of earthquake sequence, we make numerical imitation for the obstacle model.

The research of numerical imitation for the obstacle model

Earthquake is imitated as a rupture of natural occurringon fault, in order to simplify calculation in the case of having no effect on calculating result, we suppose that in linear elastic medium rupture begins from a point, then expands on the fault where there are obstacles. Initial stress on fault plane is τ_0, the crack is formed at $t=0$, its expansion follows the criterion of thebiggest main stress. Shear stress decrease from initial stress τ_0 to dynamic friction stress τ_f on the ruptured area. According to the theory of elastic mechanics, rock mechanics and fracture mechanics, writing the motive equation and boundary condition of displacement vector of any point on the fault, we make calculation by the method of finite difference. In order to inquire into the properties of obstacle outstandingly and carefully, confirm each other conveniently with experiment model, we take calculation of two dimension for the model emphatically and three dimension work is also inquired for the obstacle model. In the solution of numerical imitation, the more meticulous step T of differential time and network D are cuted, the more accurate the solution is, but it is needed for large capacity computer. In order to simplify the calculating procedure, in calculating, the dimensionless factor S is defined as:

$$S=\frac{\tau_s-\tau_0}{\tau_0-\tau_f} \tag{1}$$

where τ_s is critical value of stress, then

$$1+S=\frac{\tau_s-\tau_f}{\tau_0-\tau_f} \tag{2}$$

1+s represents normalized value of stress strength. The different strengths of fault plane are embodied by various values of 1+s, the different sizes of obstacle are shown by width D of differential network.

Fig.1 shows the rupture expansion condition of shear crack on the uniform fault, from it we can know that the crack is linear lengthen with time. Fig.2 shows the rupture expansion condition of shear crack with same size(1D) and different strengths (take the example of anti-plane shear crack), it is shown that rupture expands continuously crossing obstacle after a shorter stress concentration when strength 1+s is 3 (Fig.2a); when 1+s=5 (Fig.2b), the crack expands crossing obstacle first, then the rupture expands in the obstacle and makes it fracture fail after a shorter stress concentration; when 1+s=7(Fig.2c), it is as the same as 1+s=5, but the re-fracture time of obstacle is larger than the condition of 1+s=5; as obstacle strength is bigger when 1+s=9, the rupture expands continuously crossing obstacle, but the obstacle does not fracture finally. It is shown that all ruptures have stress concentration when they meet obstacle, and the

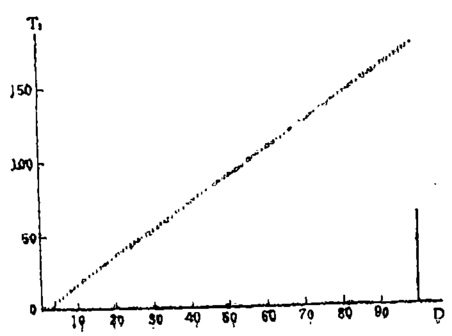


Fig.1 The expansion condition of shear crack on the uniform fault. Coordinates T_1 and T are differential time steps of anti-plane and plane respectively, Coordinate D is the space step of differential from Fig.1 to Fig.6

expansion ability of rupture is in inverse proportion to the strength of obstacle from Fig.2.

Fig.3 shows the expansion condition of shear rupture on the fault in plane where there are same strength (1+s=7) and various size obstacles. When the size of obstacle is 3D (Fig.3a), rupture meets obstacle and occurs stress concentration, then expands crossing obstacle, and makes unruptured area fracture after a period of time finally; when the size is 5D (Fig.3b), rupture makes part area of obstacle boundary fracture after a same period of time of stress concentration, then expands detouring obstacle, finally makes spare

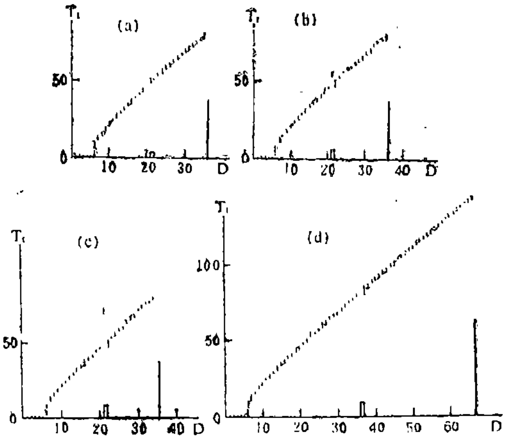


Fig. 2　The expansion condition of shear crack on the fault in antiplane where there are same size (1D) and different strength (1+s=3(a), 1+s=5(b), 1+s=7(c), 1+s=9(d) obstacles

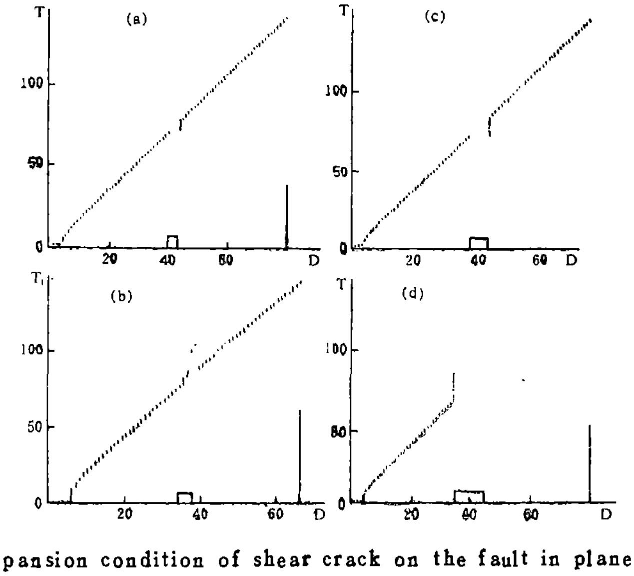


Fig.3　The expansion condition of shear crack on the fault in plane where there are same strength (1+s=7) and different size (3D(a), 5D(b), 6D(c), 10D(d)) obstacles

unruptured area fracture; when the size is 6D (Fig.3c), rupture expands crossing obstacle; when the size is 10D (Fig.3d), rupture is resisted at the front of obstacle. These results show that the rupture expansion ability is in inverse proportion to the size of obstacle.

Fig.4 shows expansion condition of shear crack in anti-plane and plane. In Fig.4a, rupture crosses the first obstacle and is resisted by the second obstacle; in Fig.4b, rupture expands continuously crossing the first and the second obstacles separately, and then makes unruptured obstacle fracture again after a period of time. We can see from Fig.4 that motive patterns of tip point of various type cracks are different each other.

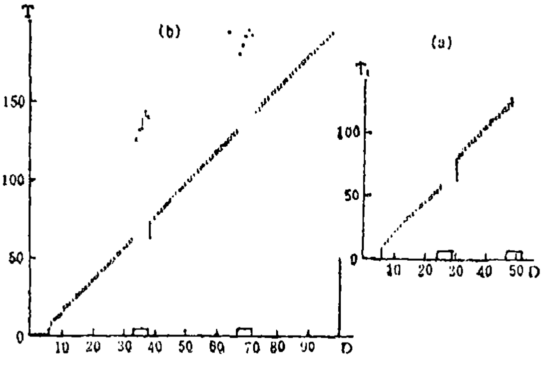


Fig. 4 The expansion condition of shear crack on the fault in antiplane and plane where there are same size(5D) and same strength(1 + s = 6) obstacles

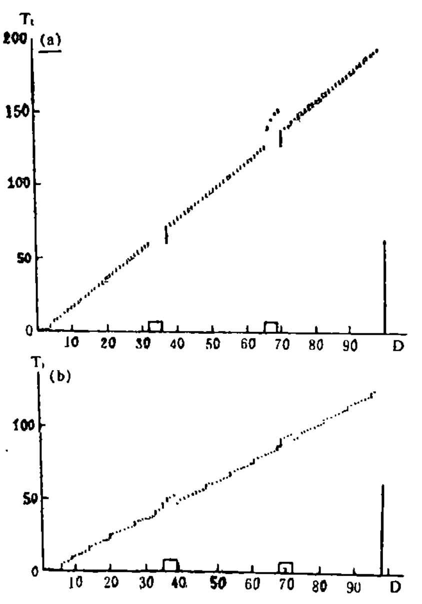


Fig. 5 The expansion condition of shear crack on the fault where there are same size (4D) and strength (1+s=6) obstacles in various media ((a)β=2.927km/s, (b)β=4.508km/s)

Fig.5 shows also expansion condition of shear crack with same size and strength obstacles in anti-plane on fault with different media. Shear wave speeds are $\beta=2.927$ km/s, $\beta=4.508$km/s respectively in Fig.5(a, b). The fracture expansion speed is also fast with high speed medium. Otherwise, the initial crack length in Fig.5(a) is shorter than that in Fig.5(b). From Fig.5(a) we can see that the rupture crosses two obstacles separately, then makes the second obstacle fracture after a period of time, but the first one is unfractured; in Fig.5(b), the rupture also crosses two obstacles respectively, but makes them fracture again right away. So the expansion of crack is related not only to the rupture speed and the rupture length, but also to the various media.

Fig.6 shows the fracture condition of three different strength and size obstacles on the fault. The middle obstacle is fractured first as it is weaker, then rupture is expanded in three ways: when it meets the first obstacle, the stress concentration is taken place, the rupture makes this obstacle fracture; when rupture expands to the third obstacle, the stress concentration is produced, as this obstacle strength is higher, the rupture expands to the end of the fault crossing the obstacle, then makes obstacle fracture again.

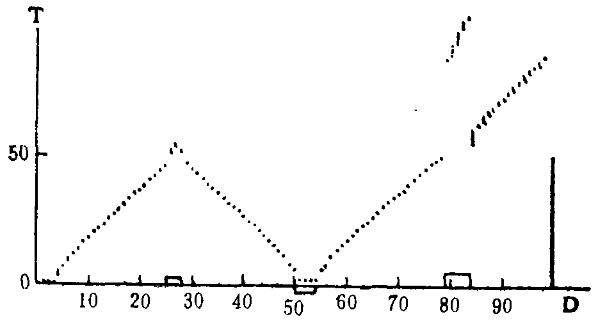


Fig. 6 The expansion condition of shear crack on the fault where there are three different size (3D, 4D, 5D) and strength ($1+s=3$, -3, 5) obstacles

From the numerial calculation we get the similar results so that of experiment[6-9]: the crack expansion ability is in inverse proportion to the strength and size of obstacle; it is related to the different arrangment forms of obstacle and to the rupture speed, the size of initial rupture area, the type of cracks and the properties of medium. The results also show that there are various fracture forms when the rupture expands to obstacle: rupture is resisted to the front of obstacle; is branched by different arrangement obstacles, and rupture expands pass through or crossing or detouring obstacles. We can get the detail process of rupture and the whole process of rupture through numerial calculation, at the same time. The calculation results prove the results of experiment imitation further. For example, a rupture can expand detouring or crossing obstacle first, then makes unfractured obstacle fracture after a period of time of stress concentration.

The application of obstacle model in the explanation of earthquake sequences

Through the research of experimental and numerial imitation for obstacle, some types of earthquake sequences can be explained with the properties and effect of obstacle:

(1) Isolated type: Earthquake of isolated type is few to occur in heterogeneous medium, unless there is only a obstacle with weaker strength and the rest is all uniform on fault.

(2) Mainshock type: If there is only one obstacle with higher strength, micro-fractures are occurred around obstacle by stress concentration, then with the stress increasing these cracks make the medium around obstacle and obstacle boundary or the whole obstacle fracture, this corresponds to mainshock. And it corresponds to aftershock that the rupture expands again and the process in which unfractured part of obstacle is fractured. So, in this condition, the type of mainshock-aftershock can be explained by obstacle model. If there is only a obstacle with high strength or some obstacles which have large difference on sizes and strengths, the type of foreshock-mainshock-aftershock can be explained. In the condition of single high strength obstacle, due to the strength is high, the rupture expansion is more complex[6], micro-fractures which occur in the medium around obstacle does not become main-fracture right away as stress concentration, but the fracture is formed in other weaker medium and expands to the obstacle, this process corresponds to foreshock. When rupture expands to the obstacle, the front of obstacle can be fractured or rupture detours obstacle after a period of stress concentration, this process corresponds to mainshock, the re-expansion of rupture corresponds to aftershock. If there are several obstacles of which differences of strengths and sizes is large, the rupture begins in the lower strength or smaller size obstacle first, this is the foreshock; the obstacles of high strength or big size are fractured locally through stress accumulation, this corresponds to mainshock, after it the rupture re-expansion can be considered as aftershock.

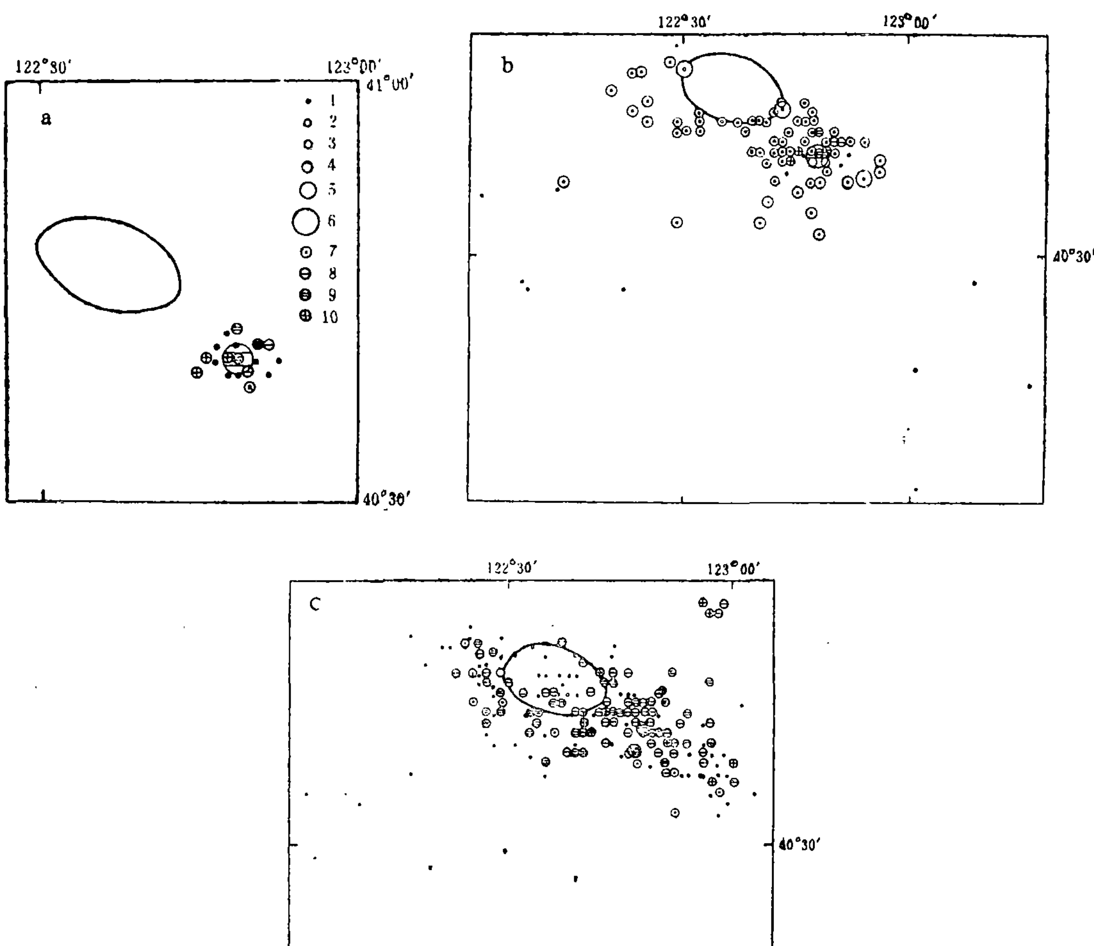
(3) Swarm type: If there are many obstacles of which differences

of strengths and sizes is not big, fracture is occurred on obstacles one after another, and the difference of the fracture strengths and releasing energy is also small, this is possibly the earthquake genesis of swarm.

According to the properties and effect of obstacle, two examples of earthquake sequences are discussed as follows:

The strong earthquake of which magnitude is Ms7.3 was taken place at Haicheng county, Liaoning Province on Feb.4, 1975, the research shows[10—14] the Haicheng earthquake is mainshock sequence typically. There are features for the foreshock[10]: The magnitude is increased unceasingly; the frequency of earthquake rises continuously; foreshock location is concentrated; the change of depth is small; the initial motion sign of p wave is consistent. Based on the analysis and inference of observation phenomena and data, the genesis of the Haicheng earthquake sequences originates from the heterogeneity of earth medium. The diagram of epicentre distribution ($Ms\geqslant1.0$) with different periods of time is drown by computer using the catalog of the Haicheng earthquakes from 1975 to 1984 precision of earthquake center is I or II category, location error $\delta\leqslant8$km(Fig.7).From foreshock sequence,we know that the fracture was formed on Feb.1, under the continue effect of structure stress, main-rupture expanded along northwest di rection, in this process, many micro-fractures were formed, they correspond to foreshock sequences, reflecting to the earth surface is that the location of foreshock is more concentrated[10](Fig.7a). The number of micro-fractures increase rapidly with increasing of micro-fracture speed, so the frequency of small earthquakes and their magnitudes all rise gradually[10]. The postponement of expansion speed and stress concentration were taken place when rupture expanded to the obstacle, namely, the earthquake frequency decreased rapidly on earth surface and temporary calm status was appearance. When stress accumulation got to some extent, the edge of obstacle was fractured, namely, main earthquake ($Ms=7.3$) was occurred. From Fig.7b we can see that there is a relevent gap in the northwest of Haicheng aftershock area, it is shown that there is a higher strength obstacle in the source body. After mainshock, the rupture expanded detouring one of sides of the obstacle, a series of earthquakes occurred in the place where the rupture passed away, then the obstacle was fractured finally after a period time of stress re-accumulation (Fig.7c,d) .It is also verified by Fig.3b and the result of 7* sample of experiment imitation. As the obstacle strength is higher, there should be some stress concentration when making it fracture, so after several bigger aftershocks were taken place in the gap of Fig.7c, namely, around the obstacle, the biggest aftershock of this sequence—the earthquake Ms6.0(Fig.7d) on May 18, 1978, occurred in the obstacle,by this time the obstacle was fractured finally.

The Xingtai earthquake (March, 1966) was a typical sequence of swarm[15—19]. We take all earthquakes (Ms≥2.0) from March 1, 1966 to Dec. 31, 1984 of which epicentre precision is I or II category and location error δ≤8km, to draw the diagram of epicentre distribution with source depth, according to different periods of time (Fig.8). There is a earthquake activity with magnitude of 3 since the 1st of March 1966 in Xingtai area, then magnitude and frequency rise step by step up to the 8th of March, Ms 6.8 earthquake was taken place, and then the biggest earthquake Ms 7.2 was occurred on the 22th again, after



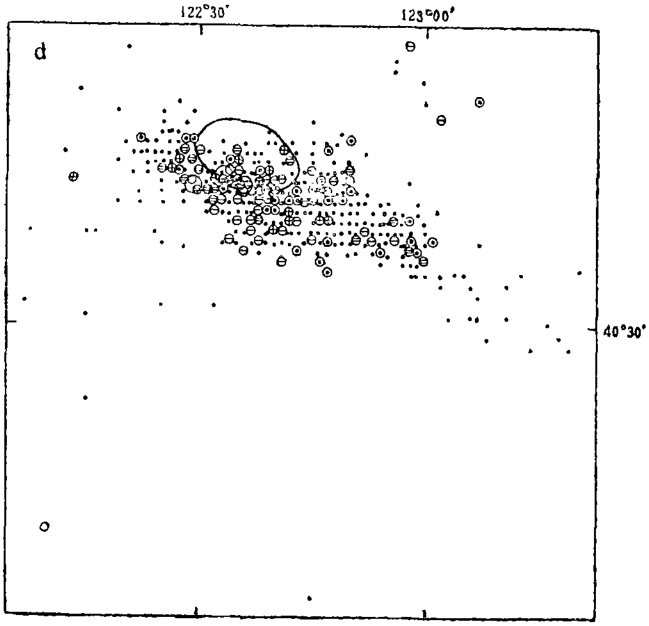
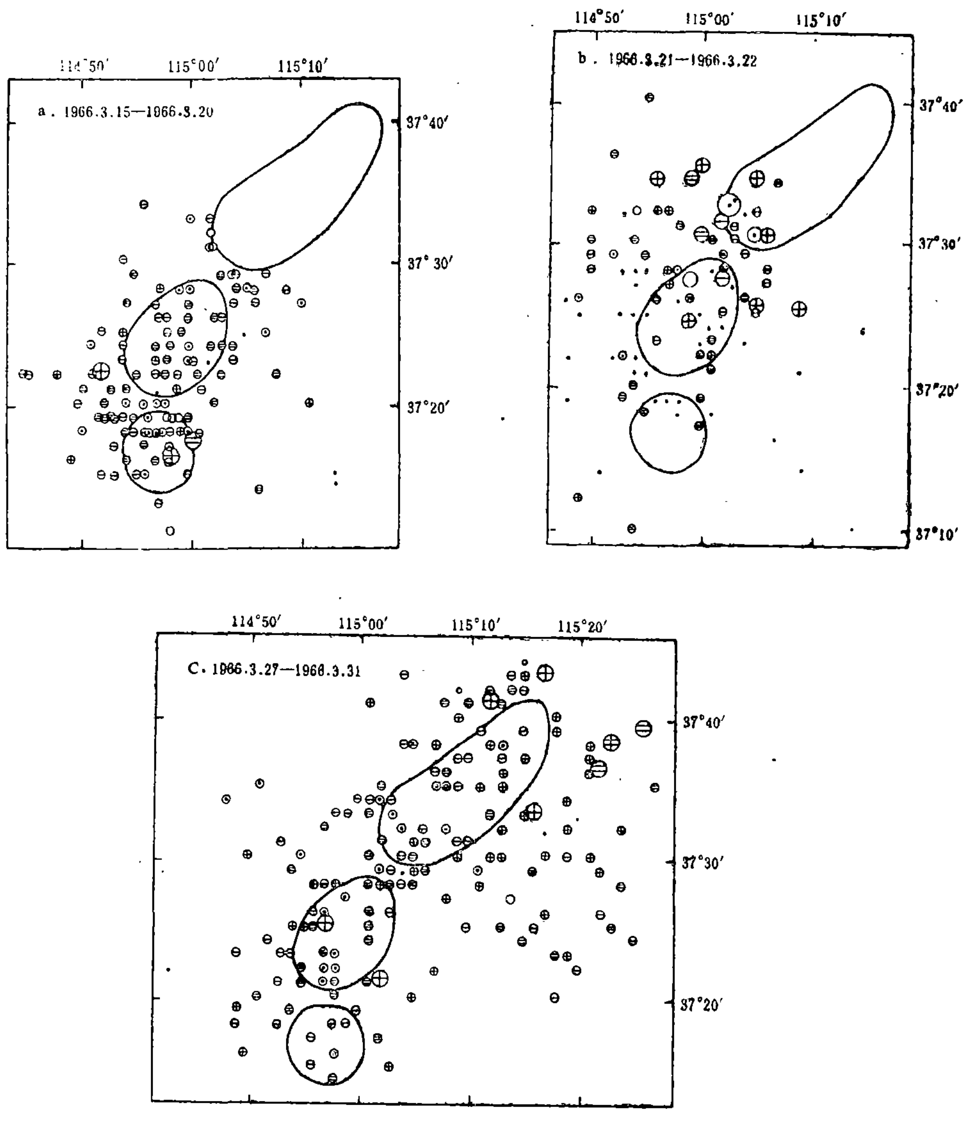


Fig.7 Distribution of earthquake center of different periods of Haicheng earthquake sequences
1.2.9>M≥1.0 2.3.9>M≥3.0 3.4.9>M≥4.0 4.5.9>M≥5.0 5.6.9>M≥6.0
6.8.0>M≥7.0 7.5.0>H≥0 8.10.0>H≥5.0 9.15.0>H≥10.0 10.25.0>H≥15.0

that, several Ms6 earthquakes were taken place continuously, and then earthquake frequency went down gradually. Through the analysis and research of observational data, it can be considered that there are three obstacles which have different strengths and sizes in underground media of Xingtai district. The middle obstacle may be a heterogeneous body itself, and it buries deeper, its strength increases from shallow to deep. The strength of southern obstacle is stronger relatively, and the strength of north one is the strongest (Fig.8). The results of Fig.6 and 34th sample in experiment show the similar case with the above. Analysing Fig.8 we can know that from March 1, 1966 to March 14, 1966, the rupture formed at middle obstacle first, and then at the south one, the place of north one was open basically at same time. From March 15 to March 20, the rupture was taken place at the south and middle obstacles continuously and the of shallow of obstacles were fractured basically, there is a tendency of rupture expansion towards northeast (Fig.8a). From March 21 to March 22, 1966, after the rupture met the north stronger obstacle, stronger stress concentration was produced, the strong earthquake of Ms7.2 was taken place, and the front of this obstacle is broken Fig.8b. The rupture expanded to north continuously, and it went detouring the obstacle after the north obstacle was locally broken. At same time, as the size at depth of middle obstacle is bigger, so it was fractured continuously (Fig.8c). From Fig.8d, we can see that the depth of obstacles broken were fractured again. It can be seen that earthquake frequency descented gradually. Because the middle obstacle buries very deep and medium strength is stronger, so the earthquakes with bigger magnitude were taken place still.

It is a feasible method that the genesis of earthquake sequence is inquired into by using obstacle method. If we know the underground structure of a certain district, it is possible to judge the type of earthquake sequence and to predict the development of the aftershock sequence, so the research for obstacle can promote the development of



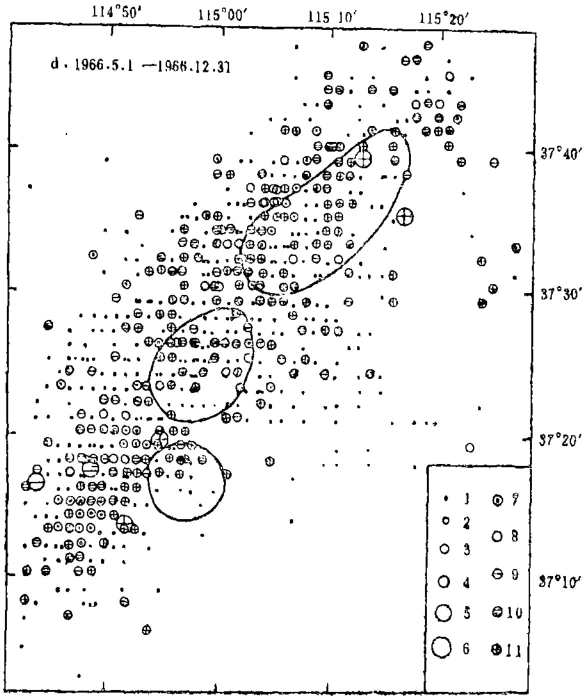


Fig. 8 The diagram of epicentre distribution of Xingtai earthquake sequence of various period times with source depths
1. 3.0>M≥2.0　2. 4.0>M≥3.0　3. 5.0>M≥4.0
4. 6.0>M≥5.0　5. 7.0>H≥6.0　6. 8.0>M≥7.0
7. 5.0>H≥0.0　8. 10.0>H≥5.0　9. 15.0>H≥10.0
10. 20.0>H≥15.0　11. 30.0≥20.0

earthquake prediction. Here, we only explain and inquire into the possible genesis of earthquake using obstacle model. If we want to predict earthquake in practical work, the geometric pattern and physical property and structure of crust medium should be determined at first, this work will be studied in the future.

REFERENCE

〔1〕张智、吴开统，地震断层面上的不均匀体研究进展概述，国际地震动态，No. 7，1985.
〔2〕Kanamori, H., An International Review, Maurice Ewing Series, Ⅳ, pp. 1—19, A. G. U. Washington, D. C., 1981.
〔3〕Lay, T., Kanamori, H. and Ruff, L., The Asperity model and the nature of large subduction zone earthquake, Earthquake Prediction Res., Vol.1, 1982.
〔4〕Das, S., Aki, K., Fault plane with barriers; a versatile earthquake model, J. Geophys. Res., Vol.82, 1977.
〔5〕Aki, K., Asperities, Bamers, Characteristic earthquakes and strong motion prediction, J. Geophys.Res., Vol.89, 1984.
〔6〕张智、吴开统，地震断层面上障碍体的实验研究，地球物理学报（待发表）.
〔7〕张智、吴开统，地震破裂扩展面上多个障碍体的实验研究，中国地震，Vol. 2，No. 2，1986.
〔8〕Zhang Zhi, Wu Kaitong et al.,An experimental study of barriers on earthquake fault plane under triaxial compression, Journal of Seismological Res., Vol. 9, No.6, 1986.
〔9〕张智、吴开统，含有障碍体的岩石样品破裂发展过程中的b值变化，中国地震，Vol.3，No.1，1987.
〔10〕吴开统等，海城地震序列的特征，地球物理学报，Vol.19，No.2，1976.
〔11〕朱传镇等，海城地震前后微震震源参数与介质品质因子，地球物理学报，Vol.20，No. 8，1977.
〔12〕林邦慧等，不对称双侧破裂过程的研究及其在海城地震的应用，地震学报，Vol. 1，No. 2，1979.
〔13〕向宏发等，1978年海城6.0级地震的构造条件分析，地震地质，Vol. 2，No. 2，1980.
〔14〕朱凤鸣等，一九七五年海城地震，地震出版社，1982.
〔15〕何志桐等，邢台地震系列的空间分布、构造应力场及其发生过程的探讨，地球物理学报，Vol.20，No.2，1977.
〔16〕王泽皋，邢台余震频度增高及以后发生的华北强震，地震学报，Vol. 1，No. 2，1979.
〔17〕滕吉文等，华北平原中部地区深部构造背景及邢台地震，地球物理学报，Vol.18，No. 3，1975.

第10卷 第2期　　西北地震学报　　Vol.10, No.2
1988年6月　NORTHWESTERN SEISMOLOGICAL JOURNAL　June, 1988

地震预报和地震对策模型体系

谭承业
（云南省地震局）

摘　　要

设计了一种用于地震预报和地震对策的模型体系。本文简述了建立这一模型体系的必要性，给出了模型体系的设计思想，讨论了模型体系的结构、功能和组成以及建立模型体系的数学方法。

（上接封三）