in Datong-Yanggao area in the near future (one month or two) was little, but the occurrence of a M_s4.0 earthquake was possible and the most dangerous date was on October 29. The fact was just that a M_s4.7 earthquake occurred in the area on that date.

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日本发生中强地震的灰色预测*

王秀文　赵丽华**　谭　勇　陈大业

（山西省地震局，太原　030002）

摘要

本文应用灰色控制系统理论，选取1980年1月至1988年12月日本的地震序列资料，将(6.0,7.0]级地震作为样本，建立了预报地震发震时刻的动态模型，并选取最佳模型对日本未来发生中强地震的时间进行了预测。另外，从函数变换的观点，对GM(1,1)模型进行了广义解释，指出对序列建模必须从满足光滑度的时刻计起。通过大量计算表明，用足够小量样本比大量样本建模，其拟合与外推精度要高。对此，从信息论的角度进行了剖析。

主题词：　日本　强震　灰色理论　模型　地震预报

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** 太行中学

GREY PREDICTION OF MODERATE AND STRONG EARTHQUAKES IN JAPAN*

Wang Xiuwen, Zhao Lihua**, Tian Yong and Chen Daye

(*Seismological Bureau of Shanxi Province, Taiyuan* 030002)

Abstract In this paper, the dynamic model of predicting the origin time of earthquakes is established by using the grey control system and choosing 6.0<Ms<7.0 seismic sequences from Jan. 1980 to Dec. 1988 in Japan as samples, and the best model is chosen to predict the occurrence of the moderate and strong earthquakes in Japan. Moreover, in view of function transformation, the model GM (1,1) is interpreted in a broad sense and the model established for the sequence must take time when the smooth degree is satisfied as the starting point. More calculations indicate that the fitting and extrapolated precisions of model established "enough small number" of samples are better than that by "large number" of samples. This is analysed from the view of information theory.

Subject words: Japan, Strong earthquake, Grey theory, Model, Earthquake prediction

1 Introduction

According to the system theory, seismic system is a multivariate complex large system and its output value, i.e. seismic time sequence, is an ordered structure. The fact shows that the observations of the seismic time sequence is a grey system, in which some informations is known and some is unknown. Therefore, its inherent law can be studied by the grey control system. In this paper, the model of predicting the origin time of earthquakes is established by using the theory and choosing M 6.0 moderate and strong earthquakes from Jan. 1980 to Dec. 1988 in Japan, and the possibility of occurrence of moderate and strong earthquakes in Japan is predicted.

2 Summary of the method and establishment of the model

Assuming a seismic sequence $f(t)$ with a certain magnitude interval and in a defined space-time domain to be given, the origin-time sequence $t_i(i=1,2,\cdots,n)$ has no law. If we choose a certain time of t_i (e.g. t_1) as the starting point, we can obtain a new sequence $t_i-t_1(i=1,2,\cdots,n)$ and call it $x^{(0)}(t_i)$. Obviously, the $x^{(0)}(t_i)$ is not a smooth function because its curve always has "knee". In order to satisfy the high-precision fitting to $x^{(0)}(t_i)$, we must first examine the smooth degree[1], delete the sequence that doesn't satisfy the smooth degree, do the mathematical transformation Φ (e.g. direct accumulation, weighted accumulation, forgot factor accumulation), get the regular progressive (or degressive) sequence $x^{(1)}(t_i)$, fit this se-

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** Taihang Middle School

quence by using mathematical method (establishing the model), predict the value of $x^{(1)}(t_i)(i>n)$ at the next time based on the model, finally restore $x^{(1)}(t_i)$ into $x^{(0)}(t_i)(i>n)$ through counter-transformation Φ^{-1} thus get the predicting value of sequence $t_i(i>n)$ at the next time[2,3].

Suppose $x^{(0)}(t_i)(i=1,2,\cdots,n)$ is a scattered function and $x^{(1)}(t_i)$ is generated by its once accumulation. We call it 1-AGO(Accumulated Generating Operation) then we get:

$$1-AGOx^{(0)}(t_i)=x^{(1)}(t_i)=\sum_{m=1}^{t_i}x^{(0)}(m) \tag{1}$$

where $x^{(1)}(t_i)$ can be solved from next differential equation

$$\frac{dx^{(1)}}{dt}+ax^{(1)}=u \tag{2}$$

Scattered responding solution is

$$x^{(1)}(K+1)=(x^{(1)}(0)+u/a)e^{-ak}+u/a \tag{3}$$

here a and u are discerning factors

$$[a \quad u]^T=[(A \vdots B)^T(A \vdots B)]^{-1}(A \vdots B)^T Y_N \tag{4}$$

where matrix

$$(A \vdots B)=\begin{bmatrix}-Z^{(1)}(2) & 1\\ -Z^{(1)}(3) & 1\\ \vdots & \vdots\\ -Z^{(1)}(n) & 1\end{bmatrix},\quad Y_N=\begin{bmatrix}x^{(0)}(2)\\ x^{(0)}(3)\\ \vdots\\ x^{(0)}(n)\end{bmatrix} \tag{5}$$

$Z^{(1)}$ is generated by the method of mean value,

$$Z^{(1)}(K)=0.5[X^{(1)}(K)+X^{(1)}(K-1)] \tag{6}$$

3 Predicting model of moderate and strong earthquakes in Japan and predicting results

3.1 Process of the data

Because the randomness of the earthquake process is very strong, the error of predicting the origin time of an earthquake can not be avoided by using any mathematical method. When the historical earthquakes are fit, the error would be larger. Therefore, we choose the reliable earthquakes which occurred recently as samples to establish the model. In this paper, we use the time sequence of monthly $6.0<M_s\leqslant7.0$ earthquakes from Jan. 1980 to Dec. 1988 as t_i and choose June 1980 as the starting point t_1, then the obtained sequence $x^{(0)}(t_i)$ is: (0,3,6,30,31,32,38,40,45,51,55,59,64,68,72,77,79,81,85,90,93,95). Finally. $x^{(1)}(t_i)$ can be got by once direct accumulation of $x^{(0)}(t_i)$.

3.2 Calculation of precision (or relating degree) of the model

Assuming that $\{x_k(t)\}$ is the predicting sequence of $\{x_1(t)\}$, the absolute difference at the time $t=l$

$$\Delta_{k1}(l)=|x_k(l)-x_1(l)|$$

The correlation coefficient of the sequences $\{x_k(t)\}$ and $\{x_1(t)\}$ is

$$\varepsilon_{k1}(l)=\frac{\Delta_{k1}(min)+\sigma}{\Delta_{k1}(l)+\sigma} \tag{7}$$

where $\triangle_{k1}(min)$ is the minimum difference value of $\triangle_{k1}(l)$, $\triangle_{k1}(max)$ is the maximum value of $\triangle_{k1}(l)$, and

$$\sigma=\begin{cases} designated\ positive\ real\ number, when\ \forall\ k\varepsilon\{1,2,\cdots,m\}, \\ x_k\ parallels\ x_1; \\ \xi\triangle_{k1}(max), \exists\ x_k\in\{x_i\}\ doesn't\ parallel\ x_1, \xi\in[0,1] \end{cases}$$

We choose $\xi=0.5$ in the paper.

The relating degree R is the mean value of ε_{k1},

$$R=\frac{1}{N_k}\sum_{l=1}^{N_k}\varepsilon_{k1}(l) \tag{8}$$

Generally speaking, the model is available only when $R\geqslant 0.6$.

3.3 Predicting model and results

According to formulas (1)—(8) and based on the models built by the different numbers of samples of $x^{(1)}(t_i)$, we predict the value of t_i on the same time scale in the future; meanwhile, based on the models built by the same numbers of samples, we predict the value of t_i on the different time scale. The calculation results indicate that the more the samples, not necessarily the better the fitting precision and predicting effect. It is better to predict the next 1 or 2 values by using the model established by the "enough small number" of samples nearly before the next time (Table 1). This probably reflects the fact that "enough small number" of samples contain the latest new and dynamic information of the sequence t_i but the samples far from the time have few information. This conclusion is favourable to earthquake prediction.

From Table 1, the predicting effect for Ms 6.0 shocks is better when choosing 6—9 samples to establish the model. If we choose 9 samples, the model is

$$x^{(1)}(k+1)=1341.431e^{0.46k}-1286.432$$

$$R=0.70$$

The result predicted by this model was that a $6.0<M_s\leqslant 7.0$ earthquake would occur in Japan from July to Oct., 1989. The fact was that a $M_s7.0$ earthquake occurred in Japan on October 29, 1989.

In addition, we used this method in 《Research Report of Seismic Tendency in Shanxi Province, 1988》 and pointed out the interval of the origin time and probability estimation of the earthquakes in China and North China from 1988 to 1990. Moreover, we reiterated this opinion at "Seismological Consideration of Nation and Capital Circle" held in Beijing in July, 1988. Five prediction opinions and the corresponding earthquakes are as follows: (1) "At least a $6.0<M_s<6.5$ earthquake or two will probably occur in China in 1988" and "the probability of earthquake occurrence is 75%". The fact was that a $M_s6.1$ earthquake occurred in South-East coastal area on October 16, 1988 and a $M_s6.4$ earthquake occurred in Lancang, Yunnan Province, on November 30, 1988. (2) "At least a $6.5\leqslant M_s<7.0$ earthquake will probably occur in China from Feb., 1988 to Apr., 1989, and the probability of earthquake occurrence is more than 80%". The fact was that a $M_s6.8$ earthquake occurred in Tanggulashan mountain area, Qinghai Province, on November 5, 1988. (3) "At least a $M_s\geqslant 7.0$ earthquake will occur in

China between Jun. , 1988 and Jun. , 1990, the most dangerous time segment is from Jun. , 1988 to Jan. , 1989 and the probability of earthquake occurrence is 83%". The fact was that M_s7. 5 and M_s7. 0 earthquakes occurred in Lancang and Gengma, Yunnan Province, on November 6, 1988. (4)"At least two 5. 5≤M_s<6. 0 earthquakes will probably occur in North China between Feb. , 1988 and Mar. , 1990". The fact was that M_s5. 7 and M_s5. 6 earthquakes occurred in Datong—Yanggao area, Shanxi Province, on October 18 and 19, 1989. (5)"A M_s≥6. 0 earthquake will probably occur in North China in 1989". The fact was that the Datong-Yanggao M_s6. 1 earthquake occurred on October 19, 1989.

Table. 1 Statistical analysis of predicting effect

A	B	C_1∈[15,22)	C_2∈[10,15)	C_3∈[6,10)	C_4∈[3,6)	C_5∈[1,3)	C_6<1	R
		D_1	D_2	D_3	D_4	D_5	D_6	
20	2	18	18	36	23	0	5	0. 56
18	2	0	5	15	40	30	10	0. 53
17	2	0	5	21	26	32	16	0. 55
15	2	0	6	18	24	24	28	0. 50
13	2	0	0	13	13	53	21	0. 51
12	2	0	0	7	7	57	29	0. 58
11	2	0	0	0	15	38	47	0. 59
10	2	0	0	0	17	42	41	0. 63
9	2	0	0	0	0	45	55	0. 70
8	2	0	0	0	0	40	60	0. 62
7	2	0	0	0	0	44	56	0. 70
6	2	0	0	0	0	25	75	0. 54
5	2	0	0	0	14	29	57	0. 68
4	2	0	0	17	0	17	66	0. 75

Note: A: the number of samples for establishing the model;
B: the number of extrapolating value;
C_1-C_6: the error interval (monthly) of the model output value and observed value;
D_1-D_6: the percentage of the samples within the corresponding error intervals;
R: the relating degree

According to the reference[4]*, 5 M_s≥6. 0 earthquakes occurred in China in 1988, and there were only 2 5. 5≤M_s<6. 0 earthquakes and a M_s≥6. 0 earthquake occurred in North China during the predicted time segment. The above-mentioned predictions indicate that the grey model is available for predicting the origin time of earthquakes. Moreover, we also used this method to give out the predicting opinion about the seismic tendency of Shanxi Province on October 26, 1989. The opinion was that the possibility of the occurrence of M_s≥5 earthquakes

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