PREDICTION OF THE HAICHENG EARTHQUAKE AND MEASURES TAKEN FOR DISASTER PREVENTION

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1. INTRODUCTION

On 4 February 1975, an earthquake of magnitude 7.3 occurred in the Haicheng region, Liaoning Province. It was the largest event in this area since the historic record began in 294 A.D. The epicentre was located in Chagou Commune, Haicheng County (40° 39' N , 122° 48' E), the intensity in the meizoseismal area being over nine degrees on the Mercalli scale.

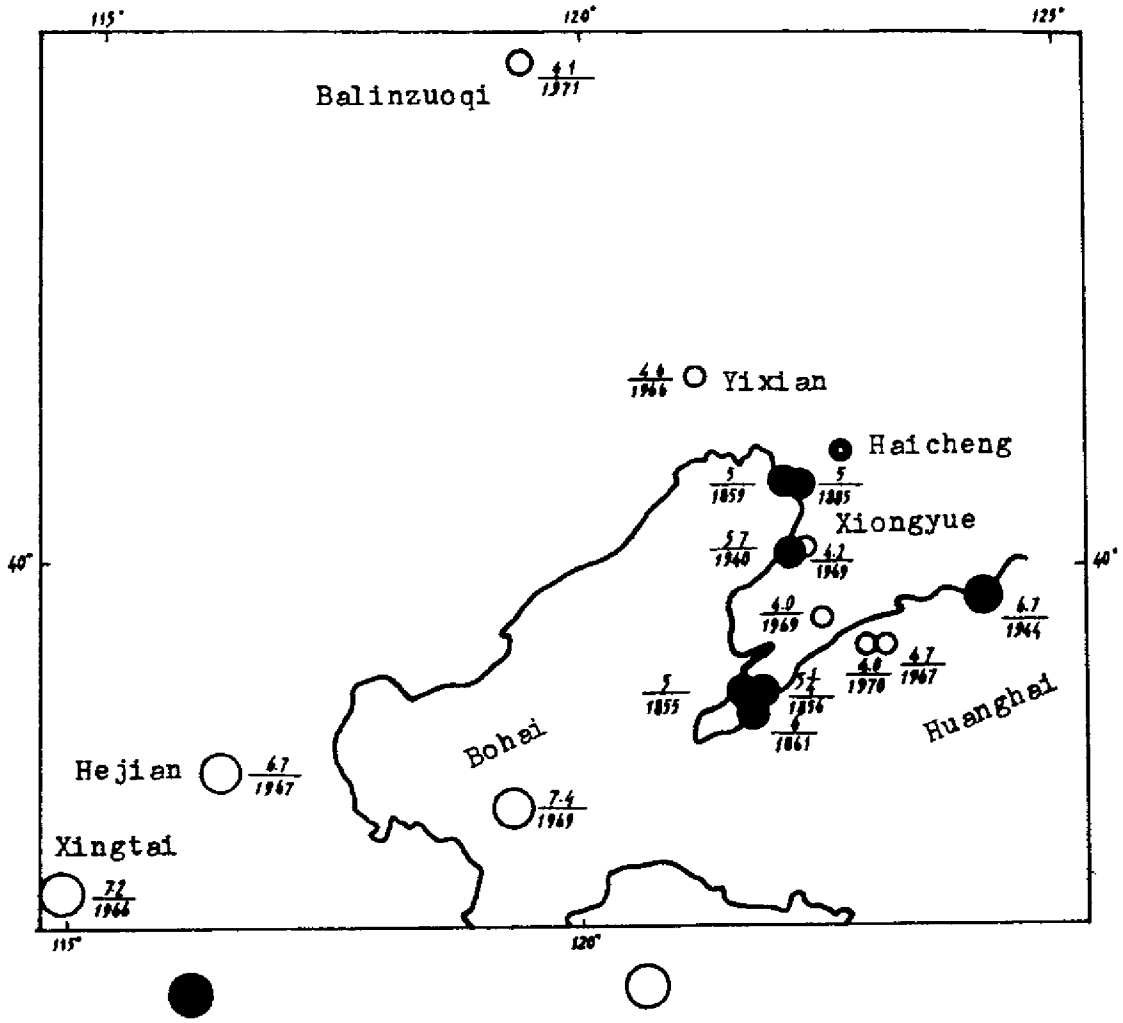
Because it happened in an area which was intensely cultivated, industrialized and densely populated, this earthquake caused damage to six cities, ten county towns and many villages in Liaoning Province. The buildings destroyed, including those in urban and rural areas, had a total floor area estimated at 22,000,000 square metres. About 2,000 bridges, big and small, were damaged and nearly 184 square kilometres of farmland were covered by sand which spouted out of the ground during the earthquake. A large amount of industrial equipment and machinery was damaged and production was interrupted by the collapse of factory buildings. Although severe damage occurred to structures and equipment, the loss of life was greatly reduced in the earthquake due to the timely prediction made by the seismological departments and the precautionary measures taken by the organized masses. 1,328 persons died in the earthquake amounting to 1.6 in ten thousand in the earthquake-stricken area.

Thanks to the great concern shown by the Party and the Government for the people of the disaster area and the assistance from other provinces, structures were rebuilt in the affected cities and towns between 1975 and 1978 with a total floor area of 4,245,000 square metres, being 83.6 percent of the total damaged area. In the country districts, rebuilding amounted to 15,800,000 square metres, being about 91 percent of the floor area lost. Soon after the occurrence of the earthquake, production was resumed and community life recovered. More recently, the cities and countryside have taken on a completely new look.

At present, earthquake prediction is still in a stage of preliminary study and research. Although one good result has been obtained in the prediction of the Haicheng Earthquake, this prediction was still empirical. We shall describe below the prediction and the precautionary measures taken.

2. METHOD BY WHICH THE HAICHENG EARTHQUAKE WAS PREDICTED

The prediction of the Haicheng Earthquake was based mainly on the empirical knowledge acquired through field investigations and research on all earthquakes occurring since 1966. The process of prediction was divided into several stages, namely long-term, medium-term, short-term and imminent. As the precursory anomalies developed, the size of the region requiring intensive observations became progressively smaller. These



1855 M=5.0 Jinxian
1856 M=5.2 Jinxian
1859 M=5.0 Yingkou
1861 M=6.0 Jinxian
1885 M=5.0 Yingkou
1940 M=5.7 Xiongyue
1944 M=6.7 Huanghai

1966 M=7.2 Xingtai
1966 M=4.6 Yixian
1967 M=6.7 Hejian
1967 M=4.7 Changhai
1969 M=7.4 Bohai
1969 M=4.2 Xiongyue
1969 M=4.0 Biliuhe
1970 M=4.0 Changhai
1971 M=4.1 Balinzuoqi

Fig.1 Distribution of Earthquake epicenters in Liaoning

observations were made by the seismological departments of our country. In distinguishing and interpreting the precursory anomalies, the method was adopted of comparing the precursory anomalies of this earthquake with those observed prior to other recent events. A comprehensive prediction was made by analysing all kinds of information acquired both at professional stations and at the many monitoring points operated by amateurs.

2.1 Assessment of the Background Seismicity - Long-term Prediction

After the Xingtai Earthquake in 1966, seismic activity in north China increased notably. In particular, the Bohai Earthquake in 1969, of magnitude 7.4, had aroused much attention. Based on an assessment of the historical and current seismic activity as well as the tectonic background, it was judged to be in danger of an earthquake. Therefore, from 1970 onward technical teams were organized for a series of field surveys and for comprehensive study of data recorded. By the end of 1973, some significant results had been produced, showing that:

a) Since 1966, the seismic activity of parts of Liaoning Province, where moderate and large earthquakes have been known to occur historically, increased in varying degrees: they appeared mainly beneath Liaoning Peninsula and the adjacent sea floor.

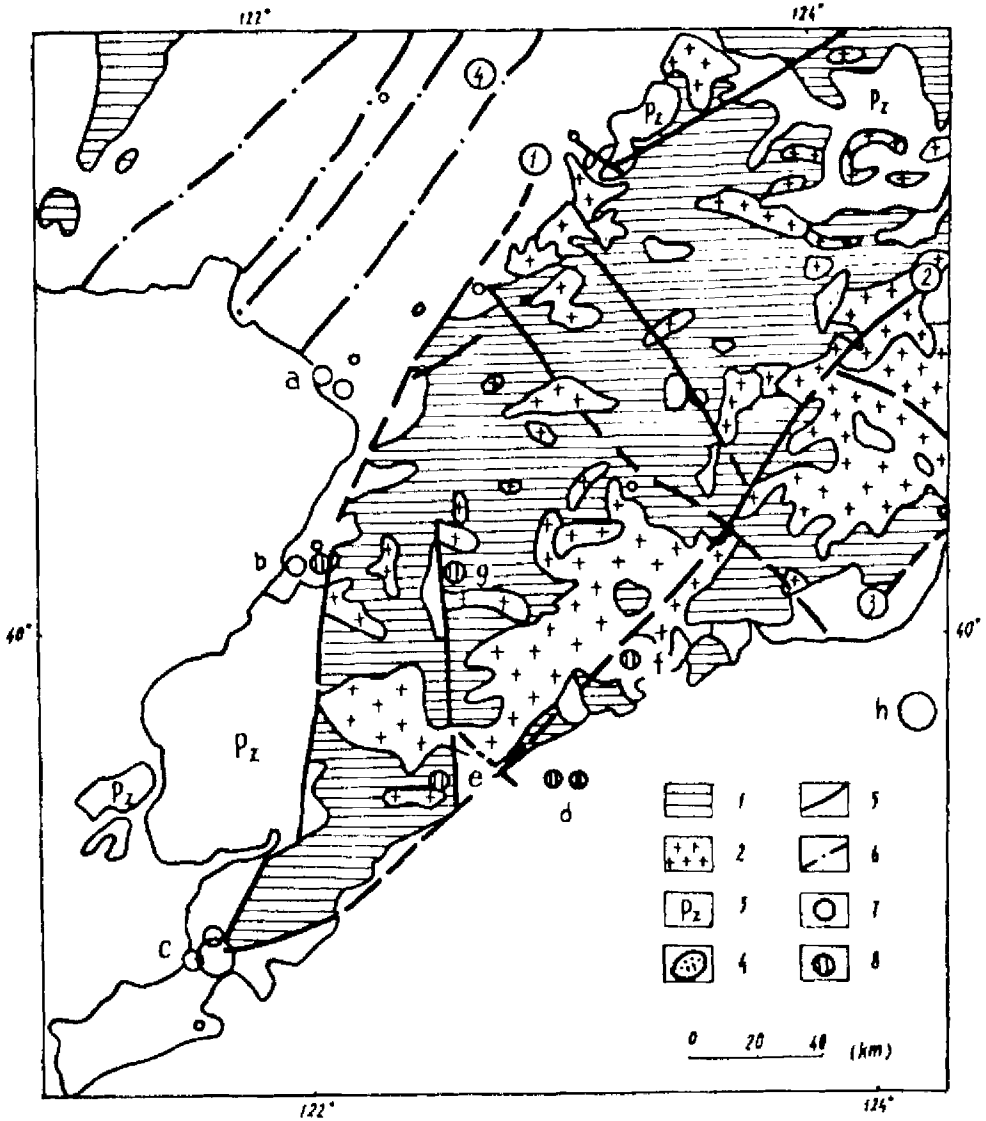
b) The main faults in Liaoning (including the Yingkow-Kaiyuan, Jinzhou, and Yalujiang faults) were coincident with the present active seismic belts, which showed that all these faults were still active (Fig. 2).

c) The observed crustal deformation on Liaoning Peninsula was considerable. The crust in Dalien and Zhuanghe rose relatively to that in Yingkow which was the centre of depression. The rate of uplift and depression was 3mm each year from 1937 to 1958, but 5mm per year from 1958 to 1970. A clear gradient of elevation change was recognized in the Haicheng-Youyan area (Fig. 3).

2.2 Medium-term Prediction of the Earthquake

In order to study the possibility that a major earthquake might occur within several years or even in one or two years, emphasis was placed, from mid-1973 onward, on strengthening all kinds of observations, including the deployment of new stations, diversification of methods of observation, and increasing the frequency of measurements of gravity, geomagnetism and land deformation. At the same time, amateur monitoring stations were developed. Thus, by the time of the Conference on Earthquake Hazard in North China, in June 1974, the following anomalies had been discovered.

a) The cumulative vertical deformation of the levelling line oriented WNW across the fault at Jinxian was 2.5 mm from September of 1973 to June of 1974, being about 20 times to the normal rate of 0.11 mm. It tilted to the NW with dip angle of 0.98 minutes (Fig. 4a).



a. 1859 M=5.0 Yingkou
   1885 M=5.6 Yingkou
b. 1940 M=5.7 Xiongyue
   1969 M=4.2 Xiongyue
c. 1855 M=5.0 Jinxian
   1856 M=5.3 Jinxian
   1861 M=6.0 Jinxian
d. 1967 M=4.7 Changhai
   1970 M=4.0 Changhai
e. 1969 M=4.0 Biliuhe
f. 1964 M=4.3 Qingduizi
g. 1972 M=4.0 Guiyunhua
h. 1944 M=6.7 Huanghai

① Jinzhou fault
② Zhuanghe fault
③ Yalujiang fault
④ Yingkou fault

1.Precambrian basement
2.Granite
3.Palaeozoic group
4.Mesozoic basin
5.Fault
6.Hidden fault
7.Historical earthquakes
8.Earthquakes occurred after 1966

Fig.2 Simplified Structurel of Southern Liaoning Province

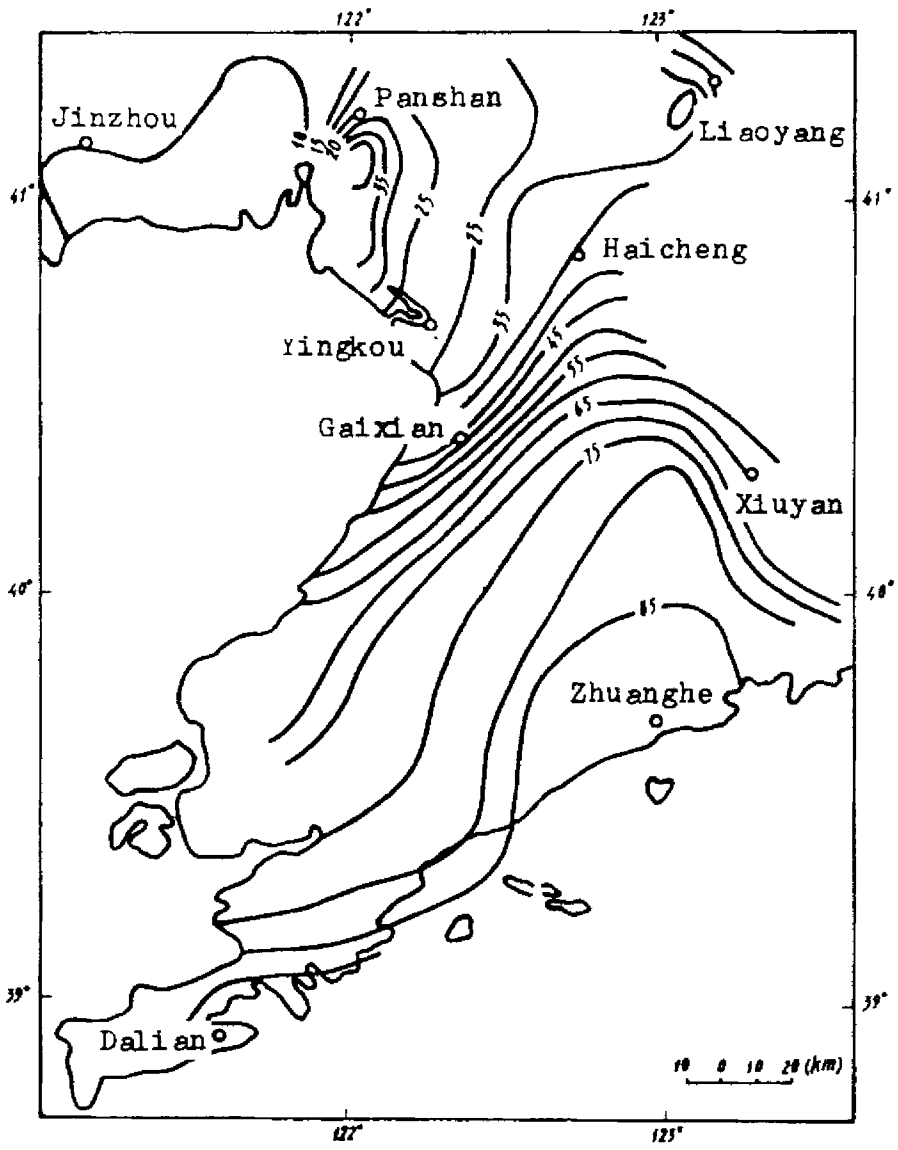


Fig.3 Vertical Land Deformation (mm) in Southern Liaoning Province

b) In the second half of 1973, the seismic activity started to increase gradually, from a frequency of 20 earthquakes each month to 35 by June 1974. The seismic activity was mainly concentrated in the southern part of Liaoning (Fig. 4b).

c) When referred to the baseline measurement in Dalian, the vertical component of the geomagnetic field was found to have increased by about 21.5 gammas, between October 1973 and May 1974 (Fig. 5a).

d) At the tide-gauge stations of Yingkou, Huludao, Qinhuangdao and Tanggu to the north of the Bohai Sea, an average sea level rise of about 10 cm was observed from 1968 to 1974 (Fig. 5b)

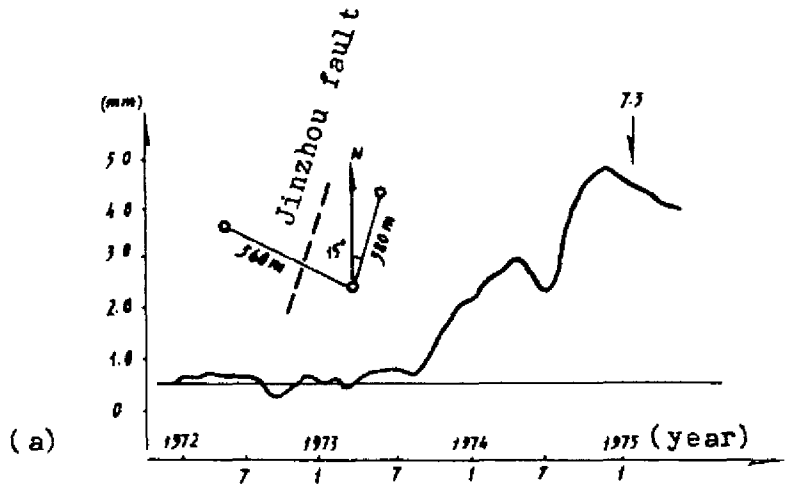
On the basis of these findings, and in view of some other abnormal factors such as the unusual meteorological change in the northern part of China, the activity of the circum-Pacific seismic belt and occurrence of deep-focus earthquakes, a medium-term prediction was made at the June 1974 Conference that there might be an earthquake of magnitude 5.0 or 6.0 in one or two years to the north of the Bohai Sea, and the meeting report was later approved by the State Council and transmitted with an order to units concerned to strengthen their observations and precautions.

2.3 Short-term and Imminent Prediction of the Earthquake

In response to the demand of the State Council, efforts to increase observations and disaster preparedness had been intensified in the latter half of 1974. The seismological departments of some provinces and cities along the coast of the Bohai Sea co-operated closely, making a common plan and exchanging information and earthquake arrival times and studying the earthquake situation at regular intervals. Hence, before the National Conference on Earthquake Prediction in January 1975, the following data on various kinds of anomalies had been collected through a six-month field survey and observations by both professional and amateur stations.

a) The seismic activity continuously increased. The moderate and small earthquakes recorded in 1974 numbered about 600, being 5 times as many as the average in the past few years. Most of these earthquakes appeared in swarms, among which the Shenwo Reservoir earthquake swarm (70 km from Haicheng) in December 1974 was most notable, in which the largest event was of magnitude 4.8 (Fig. 6).

b) The levelling anomalies at Jinxian abruptly increased after a small reversal. The cummulated total for ground deformation was as as high as 4 mm. By December 1974, many abnormal phenomena involving underground water and animal behaviour were reported first in the Dandong region, and later in other places such as Panshan, Donggou and Fengcheng. The size of anomalies increased, as also did the number of places in which the anomalies were observed (Figs. 7, 8).



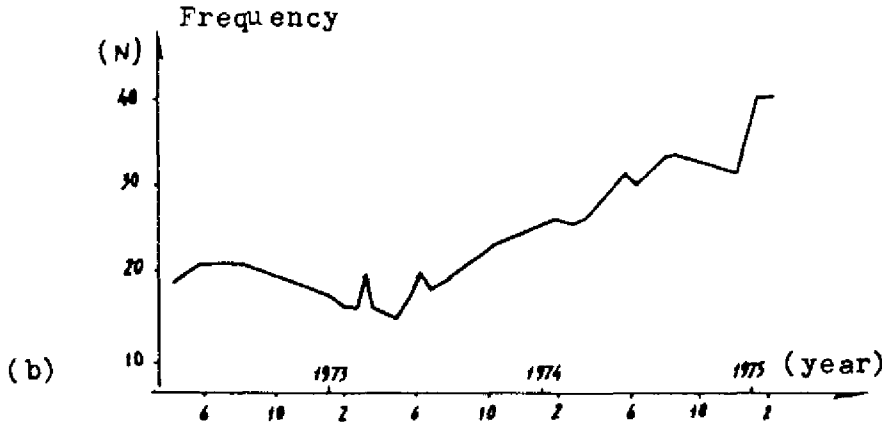


Fig.4 a. Short-line levelling curves measured at Jinxian site
b. Seismic frequency in southern part of Liaoning

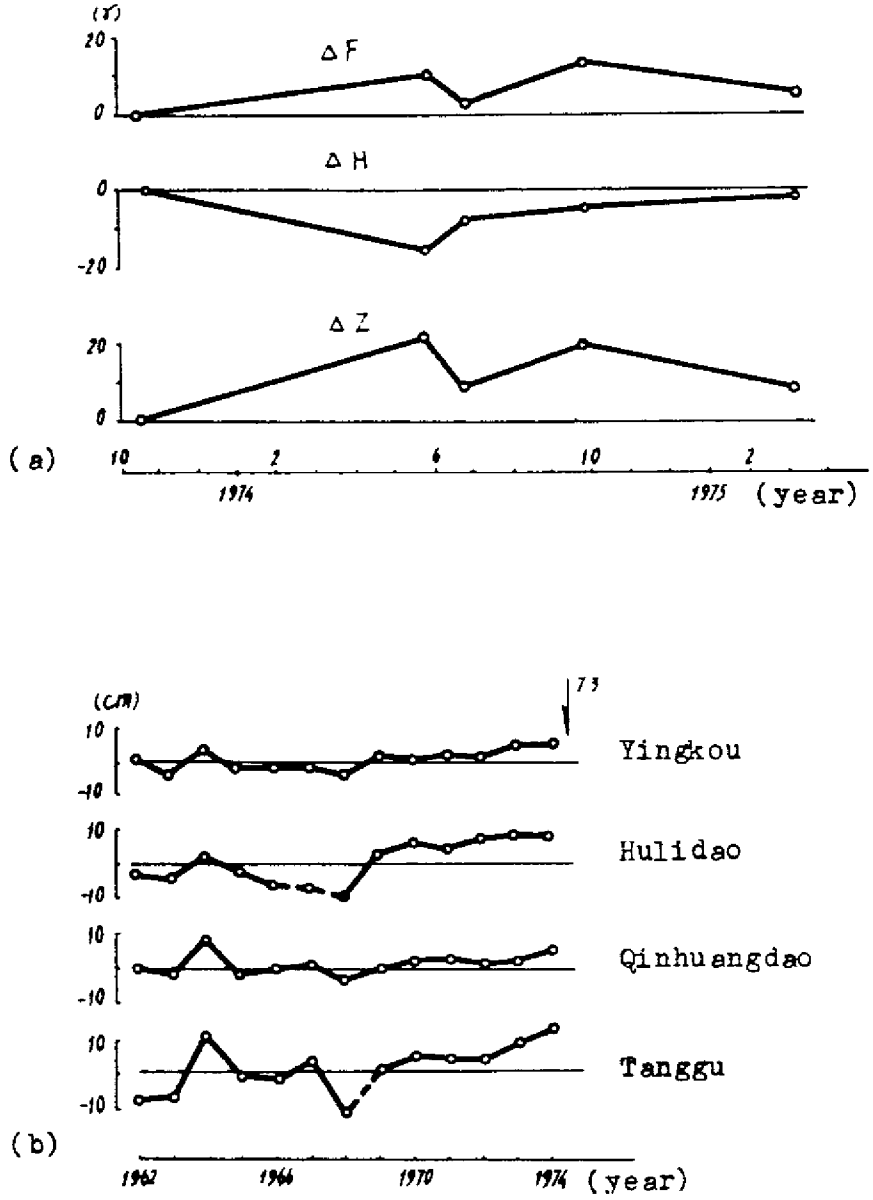


Fig.5 (a) Curves of geomagnetism recorded by Dalian station
(b) Variation of sea level in Yingkou, Huludao, Qinhuangdao and Tanggu

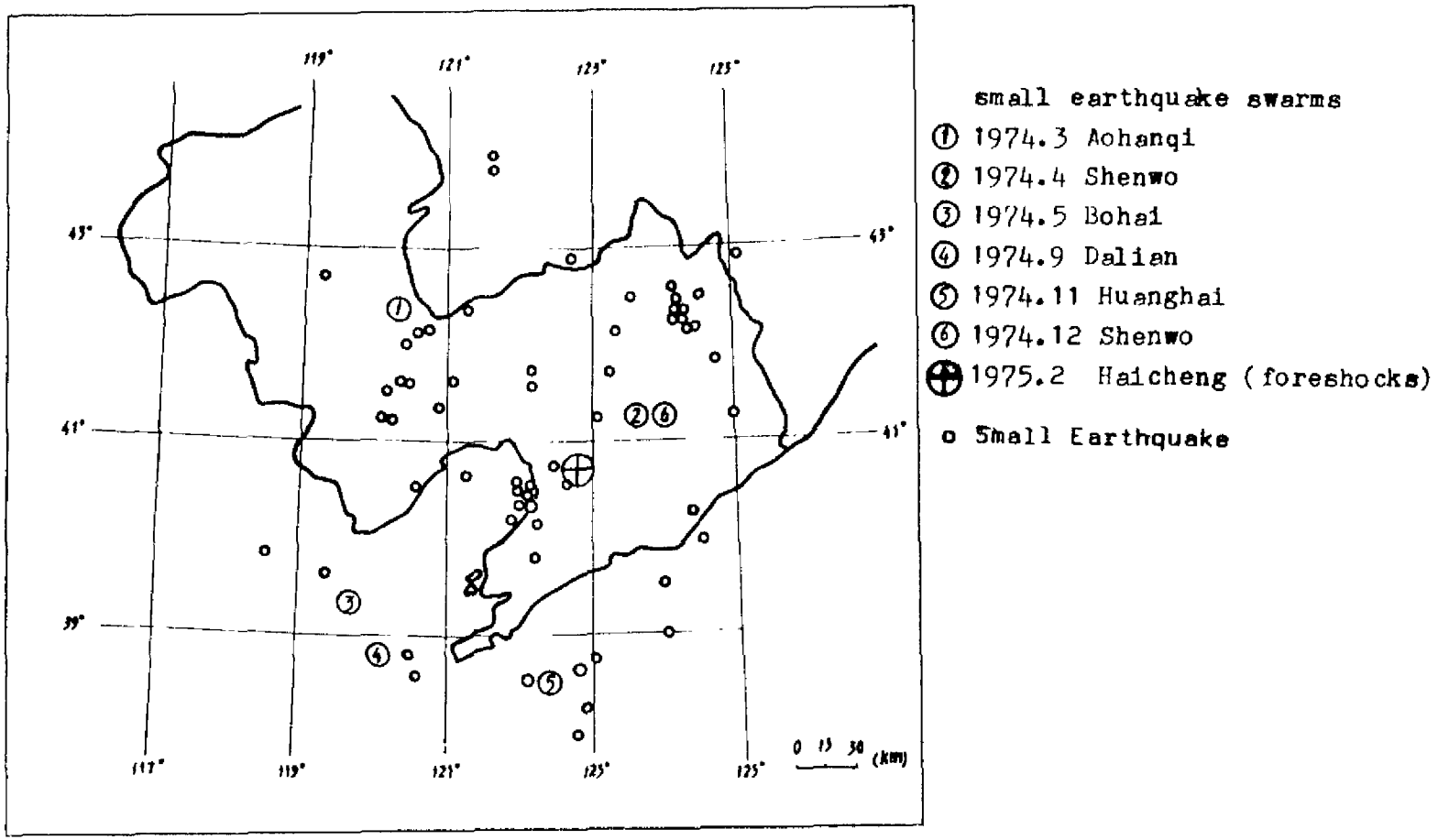


Fig.6 Distribution of small earthquake swarms

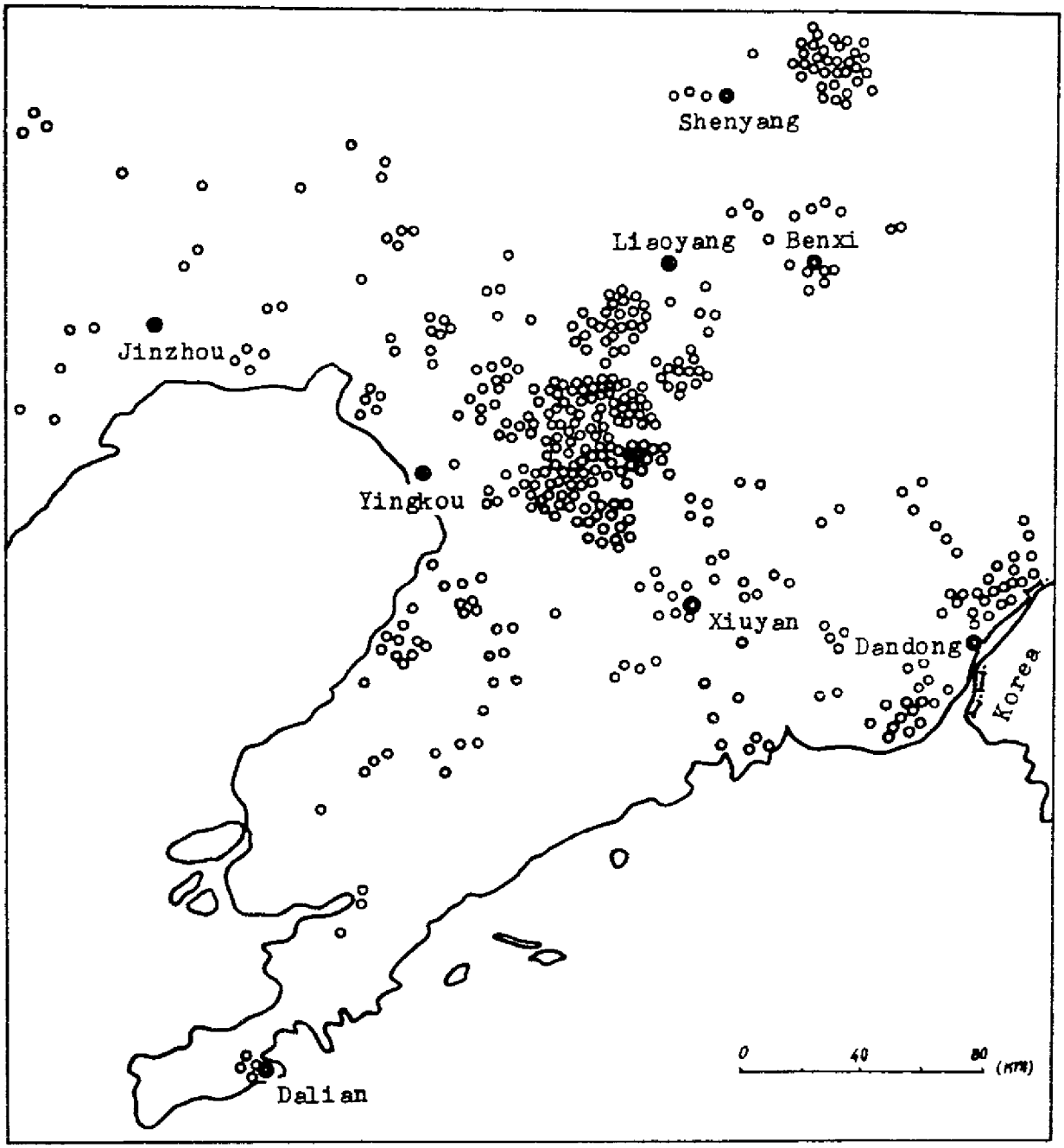


Fig.7 Points showing underground water anomalies

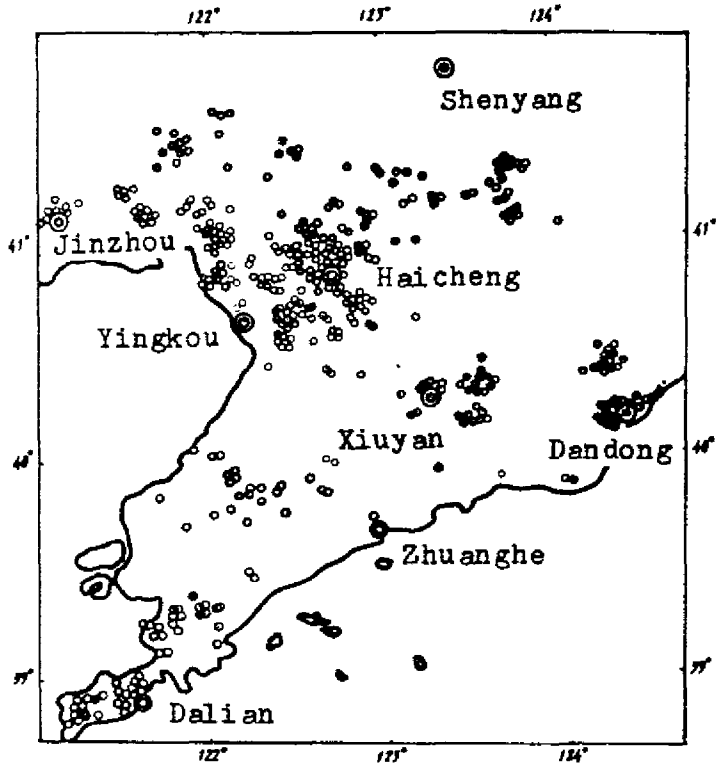


Fig.8 Points showing animal anomalies

d) Anomalies in the radon content of water appeared in Benxi and Dandong. Readings changed by as much as 40 to 70 percent (Fig. 9).

After comprehensive analysis of the above data, it was definitely proposed that Yingkow, Jinxian and Dandong might be the places where an earthquake of magnitude 5.5 or 6.0 would occur in the first six months of 1975. It was recommended that effective measures should be taken to high-light observations and precautions.

Beginning during the last ten days of January 1975, more obvious anomalies were found by both professional and amateur stations (Fig. 10). These included:

a) The anomalies of underground water increased abruptly not only in number, but also in amplitude. Water spouted out of the ground and ice was broken in ponds. Wells became artesian and some springs stopped running.

b) Reports of abnormal behaviour of animals grew in number. Some big domestic animals cried in fear, snakes came out of their caves even in winter, dogs barked crazily, geese and ducks flew away and chickens acted somewhat irrationally.

c) In the measurements of telluric currents, ground tilting and radon content, some pulse-like fluctuations appeared.

d) New earthquake swarms (foreshocks) were found within the prediction area, on the boundary of Haicheng and Yingkou. These phenomena made the people firmly believe the anticipated earthquake would soon occur. Based on all these observations, an imminent prediction was made and reported to the local government at 00.30 hours on 4 February, that a strong earthquake would occur after these small earthquakes. At 10.00 hours on 4 February, the Government of Liaoning Province alerted the whole province by telephone that a comparatively large earthquake would occur in Haicheng and Yingkou regions and that precautionary measures must be taken immediately. Nine hours later, the predicted earthquake occurred.

3. PRECAUTIONARY MEASURES FOR THE HAICHENG EARTHQUAKE

The work of carrying out observations, prediction and preparedness measures prior to the Haicheng earthquake was guided by the seismological working policy of our country, under the leadership of the Communist Party, giving first place to precautionary measures, combining professional studies with those by the masses using various kinds of instruments and relying on the broad masses to do a thorough job of prediction and preparedness. In carrying out preparedness measures before the Haicheng earthquake, a practical problem we met with was that whenever an earthquake prediction was made, and even though we confidently believed that the predicted earthquake would occur, we also recognized that it might not. Therefore, in a place like Liaoning with so large a population and industrial

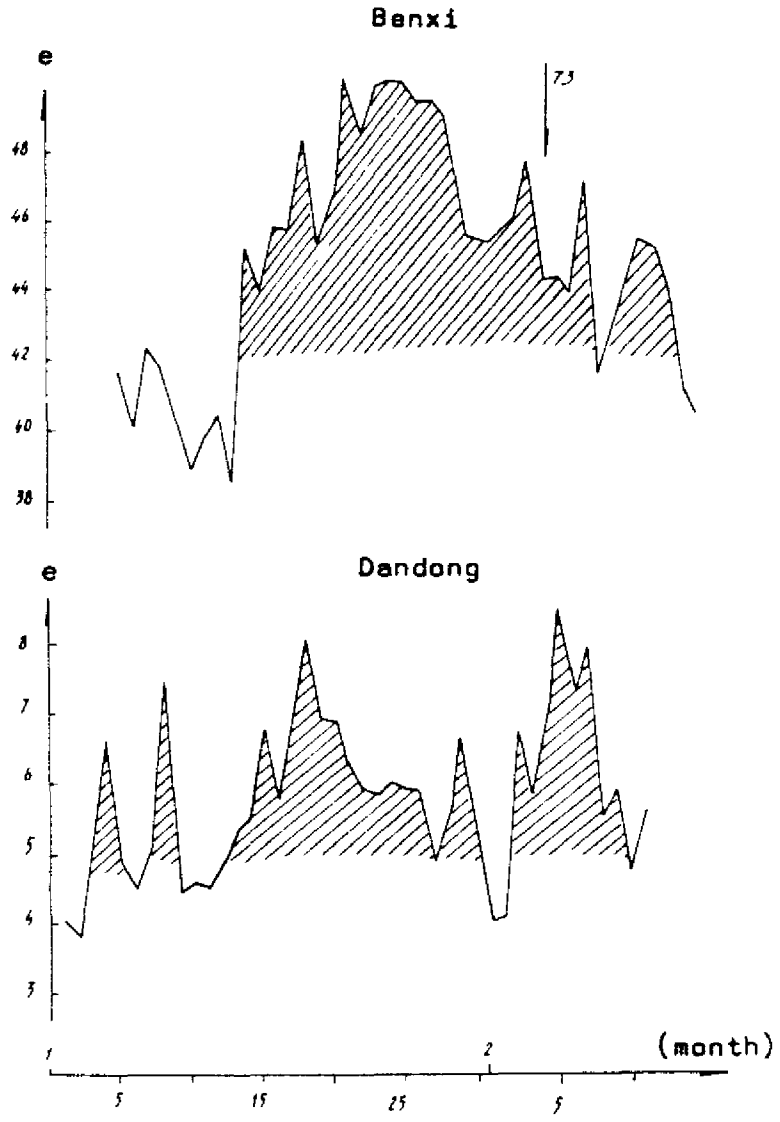
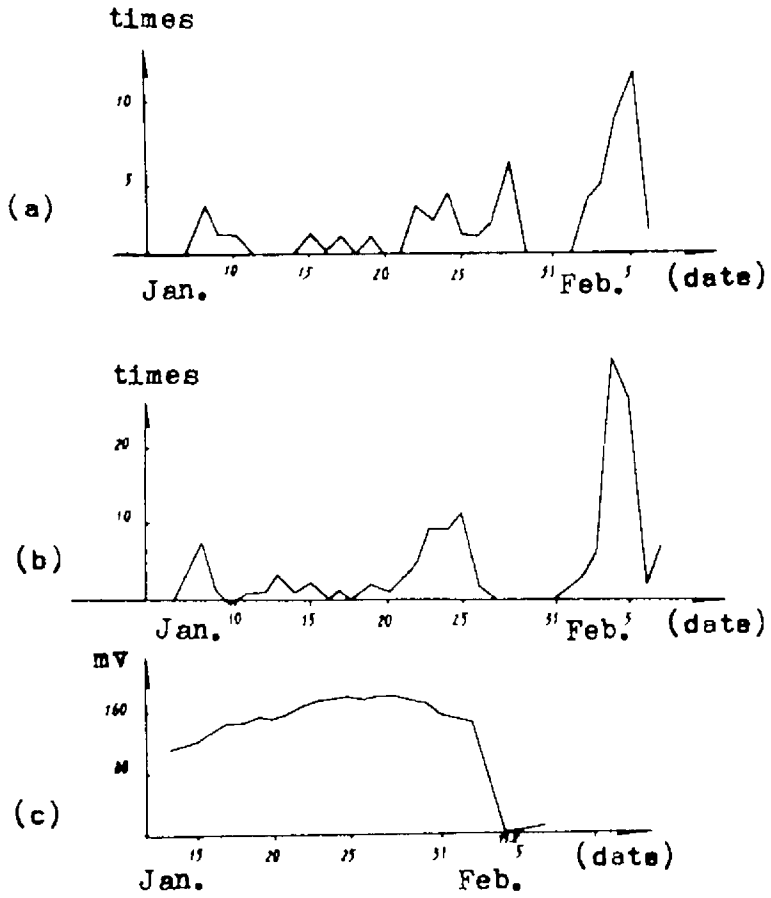


Fig.9 Abnormal curves of water radon content



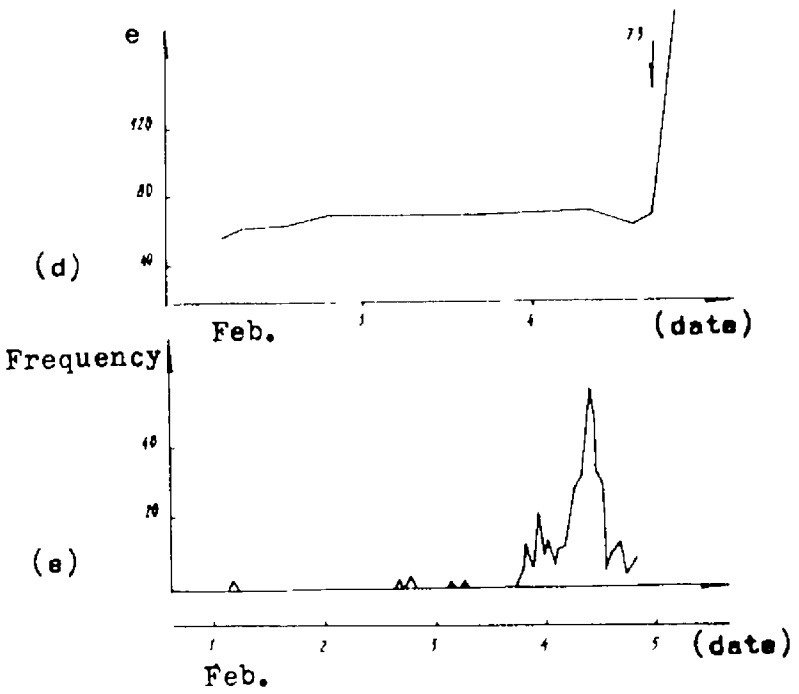


Fig.10 Anomalies before the impending earthquake

(a) Underground water

(b) Animals

(c) Natural potential

(d) Water radon

(e) Foreshocks

development, the precautionary measures adopted must on the one hand minimize casualties in case of an earthquake, and at the same time limit the disruption of the life of local inhabitants and economic losses if the predicted earthquake did not occur. In order to achieve this objective we must not only match preparedness measures to local conditions, but also establisn a well co-ordinated emergency management organization. Good results were achieved in preparing for the Haicheng earthquake because government officials of different levels directly led and organized the preparedness activities so that all kinds of measures could be implemented rapidly and efficiently.

The preparedness measures taken prior to the Haicheng earthquake included the following:

3.1 Establishment of organizations in preparation for the disaster

After the medium-term prediction had been reported, organizational structures were set up quickly in cities and rural areas in Liaoning Province to further strengthen observations and preparedness for the expected earthquake. As the earthquake became more imminent, some large factories, mines and communes in the area also set up their own organizations. Even in brigades, people were appointed to be on duty day and night, in order to maintain communications. By the time of the earthquake, there were about 1,000 different organizations.

All these organizations carried out public education campaigns on what to do before an earthquake for the masses, and at the same time mobilized and organized them to make observations and to work out preparedness plans to suit their local conditions. For example, organized by the Earthquake Prediction Headquarters of Yingkow, special teams were formed, involving many departments in Yingkow city, such as power supply, post and telecommunications, traffic and transport, materials supply, public security, hospitals and similar services. They had stored materials like food, medicine, matches, candles etc., and assembled trucks and automobiles in preparation for the disaster. They also carried out manoeuvres and training practices before the mainshock. As a further example, in the Dingjiagou Brigade, Haicheng County, a preparedness group was set up to communicate knowledge to everybody on what to do during and after an earthquake. On 3 February, the residents were organized to build lightweight emergency shelters ten metres away from the old buildings in which they normally lived. They examined the households of the old, the weak, the sick and the disabled and arranged for these persons to move to safe places. As a result, none of the 878 villagers died in the earthquake. The responsible departments had set up protective structures and put the preparedness plans into effect, thereby ensuring the maximum protection from losses during the earthquake.

3.2 Public Awareness and Education

Organized by the seismological departments of different levels,

mass education and propaganda programmes were developed in all parts of Liaoning Province half a year before the main shock. A wide range of methods and materials were used, including books, pictures, slides, broadcasting, local newspapers and public meetings. During that period, 1,290,000 books and pictures about earthquakes were distributed; about 5,900 sessions of films and slides on the subject were held; 4374 lectures were organized; 2077 training courses of various kinds for public education staff were run. Giving the public some knowledge about seismology meant that people enhanced their vigilance against an earthquake and became much less frightened, even though some people at the beginning panicked over the coming disaster. The broad masses took the initiative in the observations and found a great number of anomalies. Because the broad masses had been given basic information about earthquakes, they paid close attention to the guidance they were given and thus increased their ability to protect themselves. In short, they played an important part in the observations leading to the prediction of the Haicheng earthquake.

3.3 Matching of preparedness measures to local conditions

From December 1974 onward, Earthquake Offices at various levels authorized by the Liaoning Provincial Government, organized people in urban and rural areas to work out their own measures in accordance with their local conditions. For checking and accelerating the preparedness activities, the provincial authorities called a meeting attended by the leading cadres from five cities and the authorities responsible for railway, water conservancy, electric power, iron and steel, coal, building and oilfield systems, to make specific plans for, and carry out further research on earthquake preparedness.

It was essential that earthquake preparedness planning should not interrupt industrial production. Thus, each department made its own preparedness plans. For example, special safety requirements were set up in industrial enterprises like water supply and electric power supply. Safety tunnels were selected in some mines which offered most protection from collapse. On the railways, emergency signals were installed as a safety measure. Escape routes and evacuation routines were established in the more densely populated areas. Moreover, the places where secondary disasters were likely to occur were examined thoroughly. The production of highly inflammable or explosive materials was put under special control and it was required that these products be stored in limited quantity, so quick action could be taken in emergency. All the buildings in the cities had to be examined to determine whether they were earthquake-resistant (this work had not been finished when the earthquake occurred). Buildings were classified into several categories and evacuation areas were determined. For more important industrial facilities, emergency measures had been taken on the basis of inspection and judgement. For example, some small cracks on the cemented bank of a reservoir near the epicentre, retaining several million tons of water, had been found and filled immediately afterward with epoxy resin. An emergency rescue team was also set up in case of disaster.

The preparedness measures in rural areas were matched to local conditions. Either temporary shelters were erected or barns were used.

But people could not live inside these emergency houses for long because of the cold winter weather. Therefore, during the short-term prediction, people moved to better-insulated and well-constructed housing for the night. In the imminent stage, however, most people evacuated their houses and stayed in their shelters until the occurrence of the earthquake. But a few disbelieving individuals refused to leave their house and were injured or killed when the earthquake happened.

In general, the above-mentioned measures were well-suited to the specific conditions in the southern part of Liaoning Province. Although the short-term prediction lasted about a month, there was relatively little economic or social disruption. In the imminent stage, big enterprises such as Anshan Iron and Steel Company did not stop production until the evening of 4 February. A train between Dalian and Shenyang still ran until the earthquake-induced luminescence was seen by the train dirver. There were, however, some problems in the preparedness measures for the Haicheng earthquake. For instance in January 1975, certain regions ventured to make an imminent prediction based on poor information thereby causing unnecessary alarm and disruption. In the rural areas, the temporary houses had poor fire- and frost-resistance and as a result some people died or were injured. Obviously, such problems need to be solved in future earthquake preparedness planning.

4. CONCLUDING REMARKS.

By carefully following our earthquake prediction policy, we succeeded in predicting the Haicheng earthquake. Based on experience gained from recent earthquakes, technical means have been developed for narrowing the range for the prediction by several stages, for comparing anomalies of one earthquake with those of others, and for prediction by multiple techniques. In response to the prediction, protective measures were taken directly under the leadership of the local governments. Because confidence in prediction is at a low level at present, attention was given to the need for compromise between the fullest possible preparedness for any event which might occur, and the minimization of economic and social disruption in case the event did not occur. Because effective measures were taken in response to the situation as it developed, the potential disaster which would have been caused by the Haicheng earthquake was successfully prevented.

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DISCUSSION

Dr. Kárník drew attention to the discrepancy between the predicted magnitude of 5 to 6 and the actual magnitude of 7.3, and asked about the reasons which led the officials to consider the prediction case as seriously as they did.

Dr. Zhu replied that historical earthquakes in China show that even moderate earthquakes of magnitude 6 may cause heavy damage.

Prof. Nigg enquired about the means of communication used to inform the public: the answer was that information was channelled first through different governmental levels which took the charge of informing the public.

Dr. Zhu confirmed a comment made by Prof. Rikitake that a false prediction was made in December 1974. This prediction was the indirect cause of three deaths and local people had complained about it.